Coastal Protection and Restoration Authority of Louisiana

2022 Operations, Maintenance, and Monitoring Report

for

Grand Liard Marsh and Ridge Restoration (BA-0068)

State Project Number BA-0068
Priority Project List 18

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Preface

The Grand Liard Marsh and Ridge Restoration (BA-0068) project was funded through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) on the 18th Priority Project List with the National Marine Fisheries Service (NMFS) as the federal sponsor. The 2022 Operations, Maintenance, & Monitoring (OM&M) report for the BA-0068 project is the 1st in a series of reports to summarize monitoring and O&M activities conducted during the life of the project. This report includes monitoring data and annual maintenance inspections available through 2021. Additional documents pertaining to the BA-0068 project may be accessed on the Coastal Protection and Restoration Authority (CPRA) website at: https://cims.coastal.louisiana.gov/outreach/projects/ProjectView?projID=BA-0068 or on the CWPPRA website at https://www.lacoast.gov/new/Projects/Info.aspx?num=BA-68.

I. Introduction

The Grand Liard Marsh and Ridge Restoration project (BA-0068) is located within lower Plaquemines Parish, Louisiana, immediately adjacent to Bayou Grand Liard (Figure 1). Extensive wetland loss in this area has resulted from a variety of factors including subsidence, salt-water intrusion, a lack of sediment supply, and oil and gas activities (NMFS 2012). Over recent decades, a series of north-south oriented bayous (i.e., Bayou Long, Dry Cypress Bayou) and their associated ridges have deteriorated, resulting in large expanses of open water. The Bayou Grand Liard ridge, which separates the open bays of the Bastian Bay and Grand Liard mapping units, is the most prominent remaining ridge. The Coast 2050 land loss rate from 1983 to 1990 in the Grand Liard mapping unit was -1.7% per year and future land loss in the project area is estimated to be -1.43% per year (NMFS 2011). These projections suggested that the remaining land would be completely converted to open water by 2050 if restoration did not occur (Figure 2).

Natural ridges in southeast Louisiana are higher elevation landscape features created by repeated overbank flooding along bayous or former river distributaries (Fisk 1944) and are considered one of the multiple lines of defense in reducing storm impacts (Lopez 2006). In addition to deflecting storm surge and providing structural protection for adjacent marshes, ridges support woody vegetation which provides valuable habitat for a diversity of wildlife such as neotropical migrant birds (Providence 2009). The Grand Liard Marsh and Ridge Restoration project was designed to re-establish ridge and marsh function in the vicinity of Bayou Grand Liard through dedicated dredging, ridge restoration, and vegetative plantings (NMFS 2012, Langlois 2011). At the time of project design, the remnant ridge along Bayou Grand Liard was mainly at marsh elevation and was expected to be lost to open water in 20 years due to erosion (NMFS 2012).

To restore ridge and marsh function in the area of Bayou Grand Liard, approximately 429 acres of marsh was created and/or nourished using hydraulically dredged sediment from an offshore borrow site, and approximately 28 acres of ridge habitat was created along Bayou Grand Liard using in situ material. The total acreage of the constructed project, including containment dikes, is 492 acres. The Grand Liard Marsh and Ridge Restoration project is one of the first ridge restoration projects to be constructed in coastal Louisiana. The only ridge restoration project that had been constructed at the time of Grand Liard project design was the Fourchon Maritime Forest Ridge Restoration Project (Benoit 2016) located approximately 11 miles ENE of Grand Isle, Louisiana.

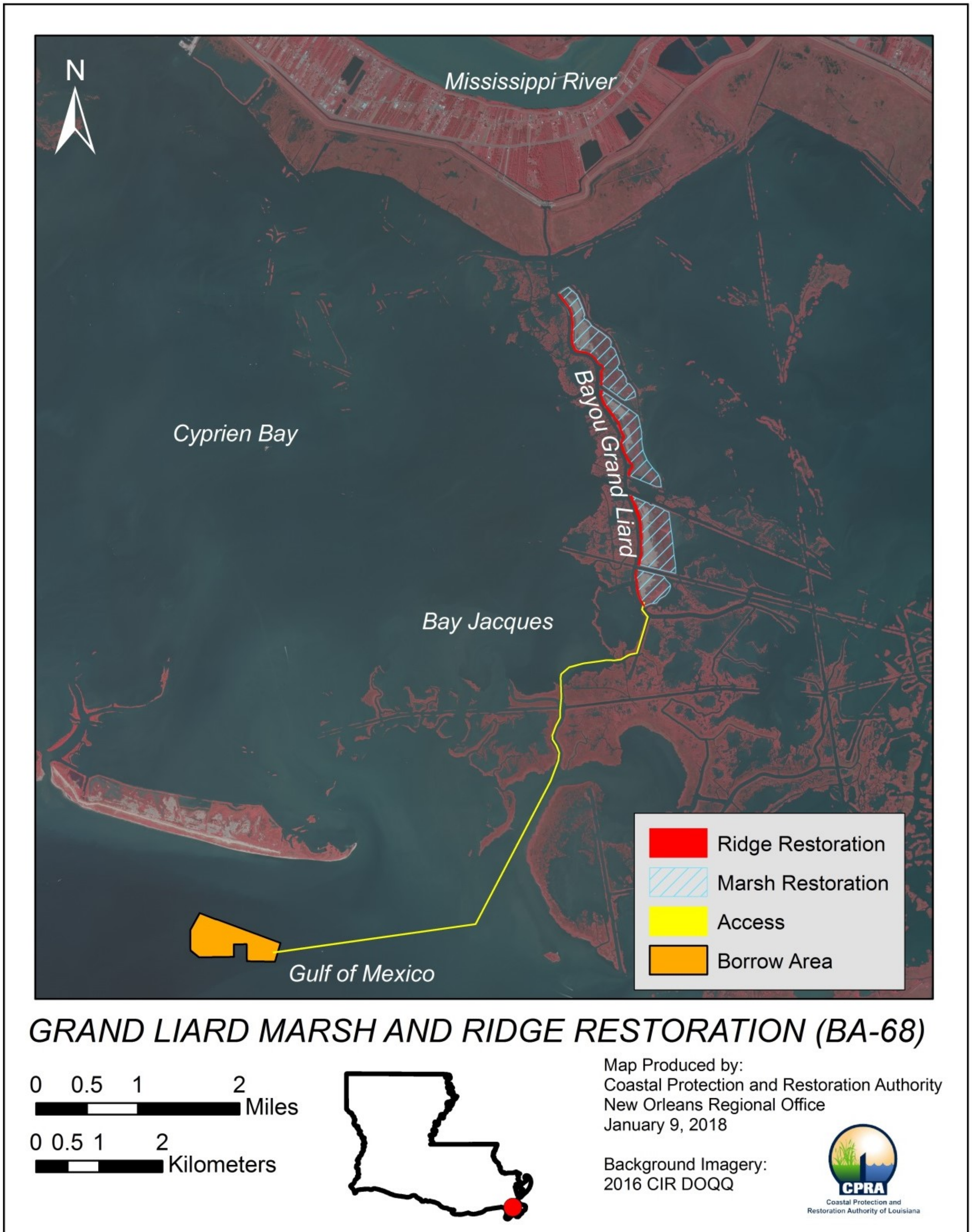

Figure 1. Grand Liard Marsh and Ridge Restoration Project (BA-0068) location, offshore borrow area location, and features.

Figure 2. True color imagery from 12/31/2009 showing remaining land within the BA-0068 boundary (indicated in red) (Source: Google Earth, USDA Farm Service Agency).

The Fourchon ridge project was constructed in two phases in 2005 and 2008 and involved the construction of approximately 5,000 linear ft of ridge and adjacent marsh utilizing sediment dredged from the Gulf of Mexico. Since construction, the Barataria-Terrebonne National Estuary Program (BTNEP) has conducted numerous experimental plantings of woody vegetation on the restored Fourchon ridge. Another CWPPRA ridge creation project, the Bayou Dupont Marsh and Ridge Creation project (BA-0048), was designed and constructed along a similar timeline to the Grand Liard Marsh and Ridge Restoration project. The Bayou Dupont project involved the creation and nourishment of over 300 acres of marsh and the creation of 10.5 acres (10,798 linear feet) of ridge adjacent to Bayou Dupont in Plaquemines Parish using sediment dredged from the

Mississippi River (Moffatt & Nichol 2018). Construction of the Bayou Grand Liard and Bayou Dupont projects were both completed in 2015.

Goals and Objectives

The goals of the Grand Liard Marsh and Ridge Restoration project are to restore the eastern ridge of Bayou Grand Liard and to re-establish marsh habitat in the open water areas to the east of Bayou Grand Liard using offshore sediment (NMFS 2012). The specific objectives of the project are to:

- Create and nourish approximately 400 acres of saline marshes and associated edge habitat for aquatic species through pipeline sediment delivery;
- Restore the Grand Liard ridge to reduce wave and tidal setup by constructing approximately 16,600 linear ft (over 20 acres) of maritime ridge habitat.

Constructed Features

Construction of the BA-0068 project began in July 2014 and was completed in September 2015 (AECOM Technology Services 2016). A total of 28,855 linear ft of earthen containment dikes were constructed around four marsh creation cells (Figure 3) using sediment dredged from within the project area. The dikes were constructed to the design template of +4.5 ft crest height, 5 ft crown width and side slopes of 5H:1V. All constructed target fill elevations were relative to the North American Vertical Datum of 1988 (NAVD88, Geoid03 Model) in feet.

The earthen ridge was constructed along Bayou Grand Liard using sediment dredged from both Bayou Grand Liard and the marsh creation areas. Although it was reported in the construction completion report (AECOM Technology Services 2016) that 15,484 linear ft of ridge were constructed, the total linear footage based on the as-built centerline survey was 16,769. The ridge was constructed to a crest height of +4.5 ft NAVD88, a crown width of 20 ft, and side slopes of 7H:1V. The earthen ridge was designed for an average 20-year target elevation of +3.0 ft. Design surveys determined that the crown elevation of the existing remnant ridge ranged from +1.0 to +3.9 ft. The 20-year target elevation of +3.0 ft was selected to allow for the ridge to still be above marsh elevation and still function as a ridge at year 20.

Following completion of the earthen ridge and containment dikes, the four marsh creation areas were filled with approximately 2,834,000 y^3 of sediment dredged from the Gulf of Mexico. The target fill elevation was +2.8 to +3.5 ft, with average constructed elevations for the four marsh creation cells of 3.3, 2.9, 3.4, and 3.4 ft NAVD88. The marsh fill elevation was expected to settle to intertidal range within three to four years post-construction and remain intertidal for the duration of the 20-year project life. The total acreage of the marsh fill cells based on the as-built topographic survey is 429 acres.

Planting of woody vegetation on the ridge was expected to occur at approximately 3 years post-construction or as soon as soil salinities and elevations stabilized; however, soil salinities along the constructed ridge did not reach levels conducive for planting until 2020 (5 years post-planting). In June 2020, the ridge was planted with 3,650 woody saplings including *Morella cerifera* (wax

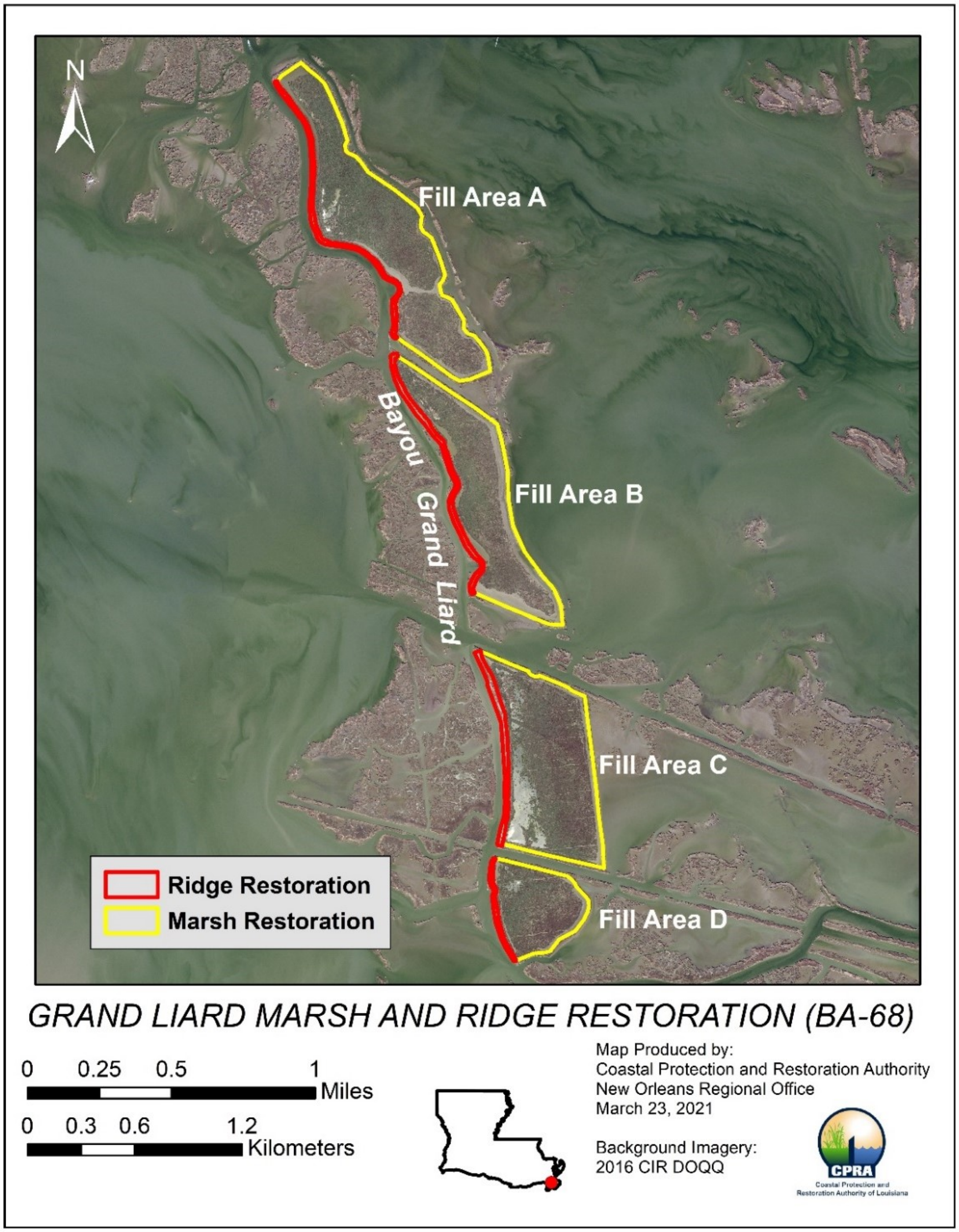

Figure 3. Location of the BA-0068 marsh and ridge restoration areas.

myrtle), *Celtis laevigata* (sugarberry), *Morus rubra* (red mulberry), *Ilex vomitoria* (yaupon), *Quercus virginiana* (live oak), *Diospyros virginiana* (common persimmon) and *Callicarpa americana* (beautyberry). The seedlings were planted along the ridge on 7-foot centers in two rows spaced 10 feet apart (Figure 4). Table 1 shows the number of trees by species planted in each marsh creation cell. Some areas of the ridge containing dense colonies of *Phragmites australis* (common reed) could not be planted, primarily in Area A. The ridge will be periodically assessed for the presence of the invasive tree *Triadica sebifera* (Chinese tallow). If necessary, *T. sebifera* will be eradicated through the use of chemical spray and manual removal. Planting of the marsh platform with *Spartina alterniflora* (smooth cordgrass) and *Paspalum spp.* (crowngrass) was expected to occur in spring 2018; however, this planting was not necessary as the marsh platform had self-vegetated by that time with *S. alterniflora* as the dominant species.

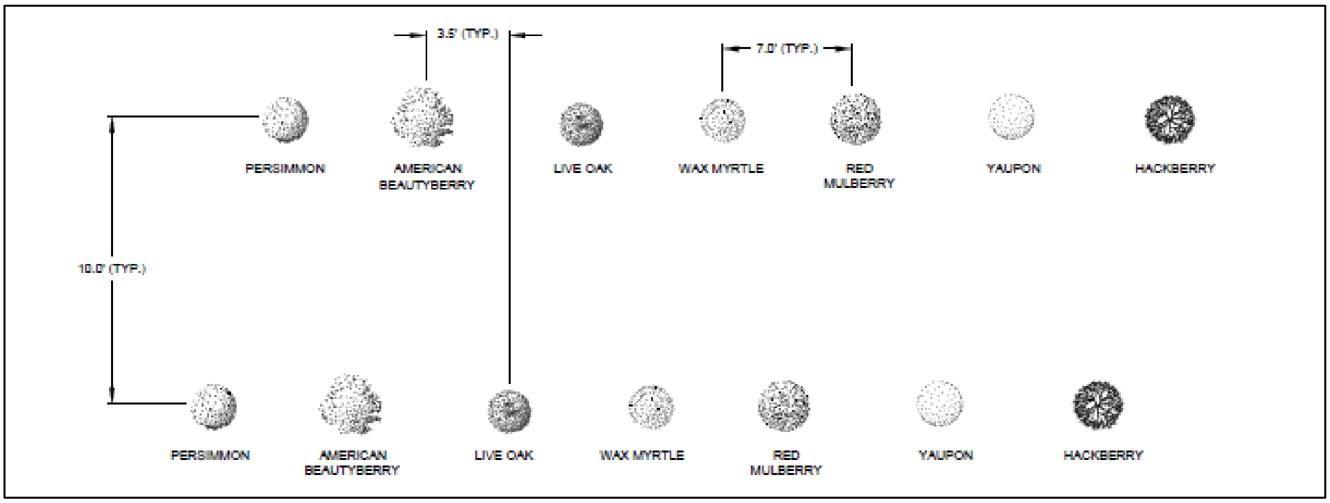

Figure 4. Layout of the woody seedling planting conducted along the BA-0068 ridge in June 2020.

Table 1. The number of trees planted by species and by marsh creation cell at the BA-0068 project in spring of 2020.

Scientific Name	Common Name	Number of Trees Planted Cell A	Cell B	Cell C	Cell D	Total
Callicarpa americana	Beautyberry	45	143	172	90	**450**
Celtis laevigata	Sugarberry	105	184	153	133	**575**
Ilex vomitoria	Yaupon	97	284	226	143	**750**
Morella cerifera	Wax Myrtle	52	183	74	1	**310**
Morus rubra	Red Mulberry	97	300	189	157	**743**
Quercus virginiana	Live Oak	156	328	127	146	**757**
Diospyros virginiana	Common Persimmon	0	14	21	30	**65**
	Total	**552**	**1436**	**962**	**700**	**3,650**

II. Maintenance Activity

a. Project Feature Inspection Procedures

The purpose of the annual inspection of the Grand Liard Marsh and Ridge Restoration project (BA-0068) is to evaluate the constructed project features, to identify any deficiencies, and to prepare a report detailing the condition of project features and recommended corrective actions needed. The inspection procedure consists of a site visit by land or water, as appropriate, with a visual inspection of the project features. Should it be determined that corrective actions are needed, the CPRA shall provide in the report a detailed cost estimate for engineering, design, supervision, inspection, and construction contingencies, and an assessment of the urgency of such repairs (O&M Plan, CPRA 2020). The annual inspection report also contains a summary of maintenance projects, if any, and an estimated projected budget for the upcoming three (3) years for operation, maintenance and rehabilitation. The three (3) year projected operation and maintenance budget is shown in **Appendix A**.

Barry Richard and Melissa Hymel of the CPRA conducted an inspection of the Grand Liard Marsh and Ridge Restoration project (BA-0068) on November 30, 2021. There was a light wind and mostly clear skies during the inspection. Photographs of the inspection are included in **Appendix B** of this report.

b. Inspection Results

Marsh Restoration Areas

The containment dike along the eastern side of Fill Area B has mostly eroded away but the marsh interior appears to be intact and vegetating. The remaining three fill areas show no signs of major erosion or land loss. The fill areas have varying degrees of vegetation but all appear to be over 80% vegetated.

Ridge Restoration Area

The ridge restoration area shows only minor erosion along Bayou Grand Liard. The woody vegetation planting performance is being evaluated and results are presented in the Vegetation section (Section IV.c.) of this report. Two hurricane events (Zeta in 2020, Ida in 2021) have impacted the ridge since the plants were installed. A significant amount of rack, primarily consisting of *P. australis* (roseau cane) reeds, from the hurricane events was noted along all portions of the ridge but this did not appear to significantly impact the plantings.

Sheetpile Closure Structures

While there is no money in the O&M budget to perform any maintenance or removal of the sheetpile structures, they will continue to be monitored during the annual inspections to demonstrate project effectiveness. Only the structures along Bayou Grand Liard were inspected (4 of 9), and of those, there was only one which was slightly exposed but still functioning as designed (Fill Area A).

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

- No immediate repairs are necessary at this time.

ii. Programmatic/ Routine Repairs

- Continue to monitor the condition of the ridge and fill areas.

d. Maintenance History

During the winter of 2015, an agreement was entered into by the CPRA and the Barataria-Terrebonne National Estuary Program (BTNEP) for BTNEP to collect and grow woody stemmed vegetation species for CPRA to have planted along the ridge. In 2019, 280 trees were planted throughout the ridge platform to assess the conditions and how they may affect a larger planting effort. In June, 2020, 3,650 saplings were planted in the ridge platform where space was available.

III. Operation Activity

Operations are not required for this project.

IV. Monitoring Activity

a. Monitoring Goals

The following specific monitoring goals will be used to evaluate the success of the project, as specified in the BA-0068 Monitoring Plan (Hymel 2020):

1) Achieve a year-10 average elevation of approximately +1.4 ft NAVD88 within the marsh fill area, and a year-10 average elevation of approximately +3.0 ft NAVD88 on the ridge. Most settlement is expected to occur by year 10; therefore, year-10 elevation targets are nearly identical to year-20 targets.

2) Reduce the "future without project" projected land loss rate of -1.43% per year (NMFS 2011) within the project area.

3) Increase the percent cover and diversity of herbaceous and woody vegetation species in the project area.

b. Monitoring Elements

The following monitoring elements will provide the information necessary to evaluate the specific goals listed above:

Land/Water Analyses

Analysis of aerial photography is being used to evaluate land to water ratios within the marsh and ridge creation areas over the life of the project. Land to water ratios within the project area in October 2016 were analyzed by the USGS Wetland and Aquatic Research Center (WARC) using 1-m resolution aerial photography (Z/I Imaging digital mapping camera) collected through the CRMS program. The analysis was conducted using standard operating procedures originally documented in Steyer et al. (1995, revised 2000) and further refined in Folse et. al 2020, in which all areas characterized by emergent vegetation, wetland forest, scrub-shrub, or upland are classified as land, while open water, aquatic beds, and non-vegetated mudflats are classified as water. Future aerial photography analyses are tentatively scheduled for 2024 (Year 9) and 2033 (Year 18), dependent on the scheduling of CRMS coast-wide flights which occur approximately every 3 years.

Elevation

Surface elevation data from topographic surveys are being compared over time to determine if the dredged material is settling at the predicted rate and if the marsh platform and ridge are maintaining elevations that promote healthy marsh and ridge habitat. A summary of the available RTK topographic datasets for the Grand Liard project area can be found in Table 2 and the layout of survey elevation points for the available datasets are shown in Figure 5. A topographic/bathymetric survey was conducted during project design in 2010 (Year -5) (Sigma 2010) and an immediate pre-construction survey was conducted in June/July of 2014. During project construction, as-built/progress topographic surveys were conducted as the dikes, ridge, and fill cells were completed from December 2014 to July 2015, as well as a Post-30 Day topographic survey of the marsh fill areas in 2015. During the post-construction period, surveys were conducted in 2016 (Year 1) and 2018 (Year 3), and future surveys will be conducted in 2025 (Year 10) and 2033 (Year 18). For consistency, the post-construction surveys are being conducted along a subset of the as-built survey transects. Seven settlement plates installed along the ridge during construction will continue to be surveyed in the post-construction period.

Table 2. Summary of topographic datasets collected within the BA-0068 project area.

Survey	Date	Surveyor	Geoid Model
Design	9/2010	Sigma Consulting Group, Inc	03
Pre-Construction	6/2014-7/2014	Hydroterra Technologies, LLC	03
Process/As-Built	12/2014-7/2015	Hydroterra Technologies, LLC	03
Post-30 Day	8/2015-9/2015	Hydroterra Technologies, LLC	03
Post-Year 1	10/2016-11/2016	Hydroterra Technologies, LLC	03/12B
Post-Year 3	10/2018	Hydroterra Technologies, LLC	03/12B

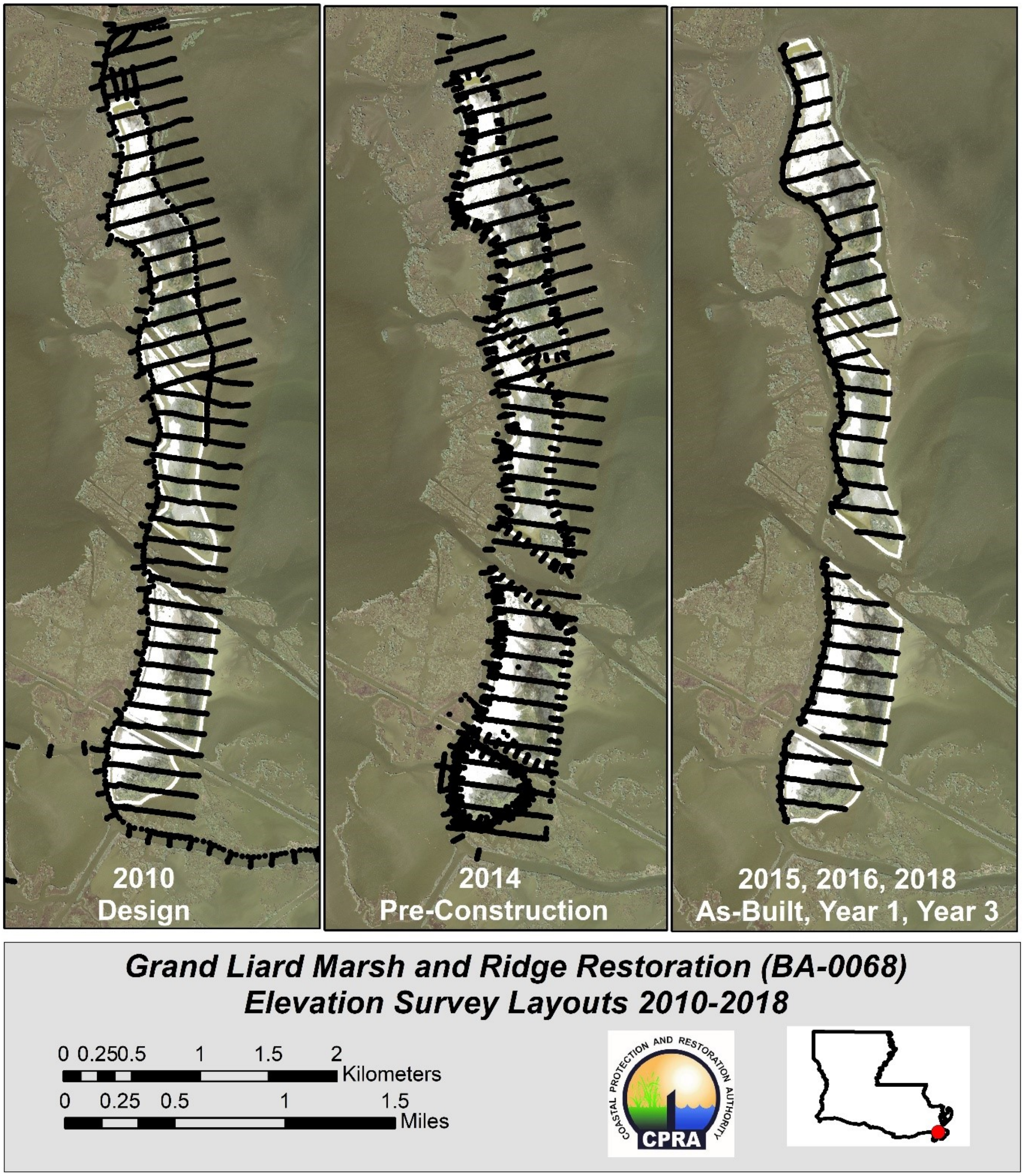

Figure 5. Layout of BA-0068 elevation survey points for design (2010), construction (2014-2015), and monitoring (2016, 2018) surveys.

Vertical elevations for all BA-0068 surveys were referenced to the Geoid03 model of the North American Vertical Datum 88 (NAVD 88) in feet; however, it is preferable to analyze project elevations within the most current geoid model (Geoid12B) to reflect current conditions. The reference monument, "CRMSBA-SM-14" was utilized for all survey events and was held to the same value relative to the Geoid03 model for all surveys [0.59 m (1.95 ft)]; however, the 2018 survey provided an adjustment value to the current geoid model, Geoid12B [-0.252 m (-0.827 ft)]. All previous surveys (2010, 2014, 2015, 2016) were then adjusted to the current Geoid12B model by the same adjustment factor so that relative changes between survey years would be maintained.

Each survey dataset was re-projected horizontally and vertically to the UTM NAD83 coordinate system and the NAVD88 datum in meters using ESRI ArcMap® 10.5.1 software. For the marsh creation areas, digital elevation models (DEMs) of elevation surfaces were created from the point data sets using the Spatial Analyst>Interpolation>Natural Neighbor tool with a 1.0 m^2 (3.3 ft^2) cell size. The DEMs were then clipped to polygons covering the shared spatial extent for the different survey years to estimate elevation and volume changes within each analysis area, and the spatial distribution of elevations were mapped in half foot (0.15 m) elevation classes (Figure 10). DEMs of elevation change were created by subtracting the corresponding DEMs using the Spatial Analyst>Math>Minus tool (Figure 11). Volume change was calculated in cubic meters (m^3) using the 3D Analyst>Raster Surface>Cut/Fill function within ESRI ArcMap®.

For the ridge creation areas, triangulated irregular network (TIN) models were produced from the point data sets using the 3D Analyst>>Data Management>>TIN>>Create TIN tool and clipped to the ridge boundaries. Next, the TIN models were converted to grid models [1.0 m^2 (3.3 ft^2) cell size], and the spatial distribution of elevations were mapped in one foot (0.31 m) elevation classes (Figures 17-20).

<u>Marsh Vegetation</u>

Vegetation data was collected within the marsh creation areas to assess the colonization and transition of vegetation on the marsh platform, to compare the vegetation in the created marsh to local, natural marsh, and to gauge the quality and stability of the vegetative community. Marsh vegetation was sampled in September 2019 within 14 plots (2-m x 2-m) using a modified Braun-Blanquet sampling method (Mueller-Dombois and Ellenberg 1974) as described in Folse et al. 2020 (Figure 6). Due to the linear shape of the project area and multiple fill cells, plot locations were randomly distributed along the length of the project area to maximize representation of all areas. Vegetation within all established plots were representative of the surrounding area. Data collected within each sample plot included an assessment of total cover, species present, percent cover of each species, average height of each vegetation layer, and the depth of water on the marsh surface. Sampling of the soil porewater salinity within each plot at 10 cm and 30 cm depth was attempted, but was unsuccessful due to clogging of the sipper probe by the finely-grained clay soils. Future vegetation surveys on the marsh platform shall occur in 2022 (Year 7), 2025 (Year 10), 2029 (Year 14), and 2033 (Year 18).

Herbaceous marsh vegetation data were analyzed in a variety of ways. Percent cover and FQI (Cretini et al. 2012) were all analyzed by marsh creation cell using ANOVA in RStudio (RStudioTeam 2016). The marsh vegetation data from the BA-0068 project were compared to

CRMS 0179, which is natural salt marsh, located nearby. The 2019 BA-0068 project data and CRMS site 2019 data were compared by using ANOVA on percent total cover and FQI by site. Lastly, in order to compare community composition, non-metric multidimensional scaling (NMDS) was performed using RStudio with the Vegan Package. The NMDS analysis was performed using Bray-Curtis distances and two axes. Analysis was conducted which compared the community composition of each plot for the latest survey year for each site, as listed above for the ANOVA. At BA-0068 there were 14 plots and at CRMS 0179 there were 10 plots.

Ridge Vegetation

Herbaceous vegetation was sampled within 14 plots (2-m x 2-m) in 2019 and 2020 to assess the natural colonization occurring along the ridge following the protocol described in the above "Marsh Vegetation" section (Figure 6). At the end of the growing season in 2020, 8 understory/overstory plots (6-m x 6-m) were established at a subset of the herbaceous plots to document the development of the understory and overstory communities. These surveys followed general CRMS methodology (Folse et al. 2020). Within the 6-m x 6-m plots, all woody trees and shrubs ≥50 cm in height were identified and diameter at breast height (DBH) was measured for all specimens ≥137 cm in height. To assess survivability and growth of the planted seedlings, seven survivorship transects (500-ft) were established along the crown of the ridge in 2020. Survivorship of 1,050 seedlings, representing ~29% of the total planting, was assessed and heights measured in October 2020 (~3 months post-planting) and June 2021 (1 year post-planting). Future ridge surveys will be conducted throughout the life of the project in 2022 (Year 7), 2025 (Year 10), 2029 (Year 14), and 2033 (Year 18).

Herbaceous ridge vegetation data were analyzed using ANOVA in RStudio (RStudioTeam 2016) to investigate percent cover (always ≤ 100%), percent shrub cover, percent herbaceous cover, total percent cover (sum of individual species, can be more than 100%), and FQI (Cretini et al. 2012) by year, marsh creation cell and their interaction. Ridge understory vegetation data were analyzed by investigating number of naturally colonized versus planted individuals present, comparing number of individuals and number of stems (some individuals have multiple stems), and conducting an ANOVA on tree height by species, plot ID, and their interaction. Ridge tree survival was analyzed by species and marsh creation cell using ANOVA within each data collection event. Repeated measures analysis was conducted on survival over time because the same trees were (and will be) repeatedly assessed. During data collection, trees were noted whether they appeared stressed (e.g. no leaves, etc.), which was also analyzed by the same methods described for survival. For all analyses, it is important to remember that not all species were planted in all areas and that sample sizes differed among species and areas, which could affect the results.

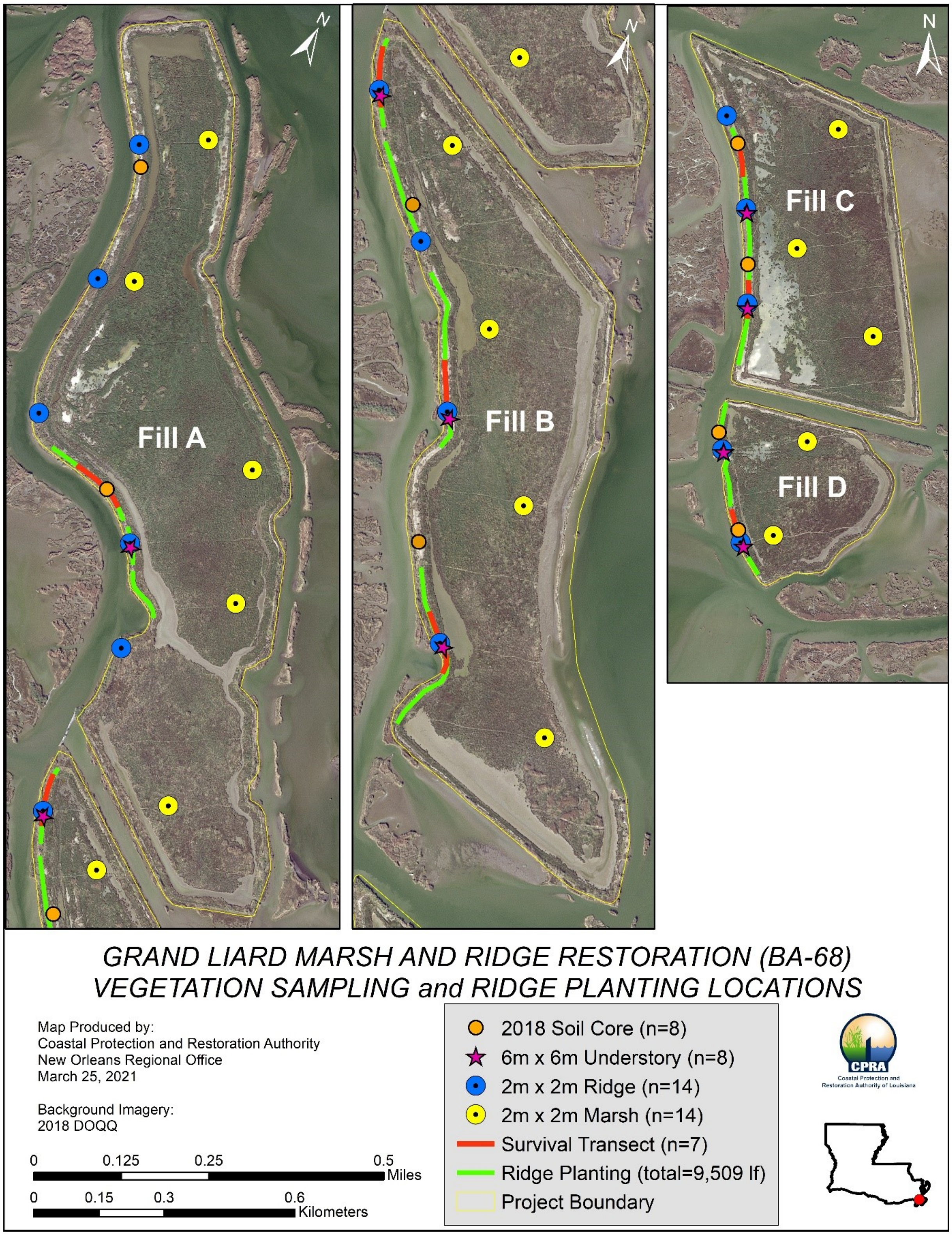

Figure 6. Location of vegetation sampling locations, soil cores, and ridge planting locations within the BA-0068 project area.

Sediment Properties
Sediment data are being collected along the constructed ridge to monitor changes in sediment properties over time. Individual soil cores were collected at 8 locations on the ridge in September 2018 (Year 3) following CRMS methodology (Folse et al. 2020), with two cores being collected along each of the four fill cells (Figure 6). Soil properties analyzed include organic matter (%), pH, specific conductance (μS/cm), soil salinity (ppt), bulk density (g/cm^3), moisture content (%), and wet/dry volume (cm^3). For each soil core, analyses were conducted in 4 cm depth increments from the surface to a total depth of 24 cm (6 total increments). Future soil analyses are scheduled for 2025 (Year 10), and 2033 (Year 18). Sediment data were analyzed by depth (pooled all cells) and by cell (pooled all depths) using ANOVA in RStudio (RStudio Team 2019). Pairwise comparisons were made using Tukey's Honestly Significant Difference test. Analyses of cell by depth could not be conducted due to lack of sufficient replication in sample collection (only two samples per cell at each depth).

Sediment samples were also collected and analyzed by NMFS from each of the four ridge sections approximately every six months after construction (Dec 2015, Jun 2016, Dec 2016, Jun 2017, Jan 2018, July 2018, May 2019) to determine if soil conditions along the ridge were amenable for planting. Four 25-cm deep soil cores were collected with a Lamotte soil sampling tube (a 30.5 cm long 2.5 cm diameter galvanized steel corer with a toothed tip) along the ridge associated with each of the four fill cells. Samples were collected from the crest of the ridge in an area that appeared visually representative of the ridge section. The four samples collected from each ridge section were then combined as a composite sample so that four composite samples (one from each section) were analyzed for each sample period. Samples were sent to the Louisiana State University (LSU) Agricultural Center's Soil Testing and Plant Analysis Laboratory (Baton Rouge, LA) for the analysis of calcium (ppm), chloride (ppm), magnesium (ppm), salts (ppm), sodium (ppm), sulfur (ppm), iron (ppm), potassium (ppm), manganese (ppm), phosphorus (ppm) and electrical conductivity (EC) (dS/m), pH, and Sodium Adsorption Ratio (SAR) using an extraction solution of 2:1 soil and deionized water. The data from 2015 through 2018 were analyzed as part of a thesis (Chatelain 2016). The results of the analysis presented in this report will follow the analytical methods of that thesis, updating the results with the 2019 data set. Sediment data were analyzed by time (pooled all cells) and by cell (pooled all times) using ANOVA in RStudio (RStudio Team 2019). Pairwise comparisons were made using Tukey's Honestly Significant Difference test. Analyses of cell by time could not be conducted due to lack of sufficient replication in sample collection (only two samples per cell at each time).

Additionally, a similar project called Fourchon Ridge was constructed from 2003 to 2008 and planted with woody and herbaceous species. Analysis of soil and plant survival data in this project allowed for the establishment of threshold levels required for 50% survival of woody vegetation for four soil characteristics including EC, salts, sodium, and SAR (Benoit 2016). These threshold levels will be used to analyze the suitability of the soils at the Grand Liard Ridge for supporting woody vegetation.

c. Monitoring Results and Discussion

<u>Land/Water Analyses</u>

Analysis of aerial photography is being used to evaluate changes in land to water ratios within the marsh and ridge creation areas over the life of the BA-0068 project. Specific objectives of the project included in the BA-0068 Environmental Assessment (NMFS 2012) were to create and nourish approximately 400 acres of marsh habitat and over 20 acres of maritime ridge habitat. During project development, an estimate of land to water ratios within the proposed project area in the year 2010 was prepared by the USGS for the Wetland Value Assessment (NMFS 2011). This analysis showed an estimated 72 acres of land within the 484 acre project area (15% land) in 2010, with 58 acres remaining within the marsh creation/containment area footprint and 14 acres remaining within the proposed ridge footprint. Based on a loss rate analysis for the period of 1984-2010, the USGS proposed a 'Future Without Project" (FWOP) land loss rate of -1.43% per year (Figure 7), which was applied to the 2010 land/water acres to project FWOP land acreage. This resulted in an estimation of 53 acres of land (11%) remaining within the project area by Year 20 of the project life if the BA-0068 project was not constructed. Alternatively, there would be an estimated 399 acres of marsh and 24 acres of ridge remaining (87% land remaining) by Year 20 if the BA-0068 project was constructed (FWP). Since construction did not occur until 2015, the FWOP land loss rate would have resulted in the loss of an additional 7 acres between 2010 and 2015 (65 acres remaining by the time of construction).

Land to water ratios within the BA-0068 project area were analyzed by the USGS Wetland and Aquatic Research Center (WARC) from 1-m resolution aerial photography collected in October 2016, approximately one year post-construction (Figure 8). Results of this analysis are summarized in Table 3. Based on the as-built construction survey, the final project area boundary was revised to 492 acres (429 acres marsh fill, 28 acres ridge, 35 acres containment). Approximately one year after construction, this area contained a total of 414 acres of land (84% land), with 357 acres contained within the marsh fill areas (83%), 28 acres within the ridge boundary (100%), and 29 acres of marsh containment (83%) (Table 3). As expected immediately following construction, primary settlement of the marsh and ridge platforms occurred during this time period which will be discussed further in the Elevation Section. The BA-0068 construction completion report noted that ~450 acres of marsh (platform) were created immediately upon construction (marsh fill areas plus containment). By 2016, open water areas were observed primarily along the in situ borrow areas used for containment dike construction within each of the four fill areas indicating greatest settlement within those areas, particularly within Fill Area B. Percentage of land within the individual marsh fill areas ranged from 91% in Fill Area C to 71% in Fill Area B. The ridge boundary contained 100% land in 2016.

Compared to the estimates of land remaining within the project boundary in 2010, the project resulted in an additional 342 acres within the project boundary at Year 1 Post-construction (2016), in addition to the existing 72 acres which were nourished/maintained. Percent land in 2016 increased by 69% within the total project boundary, by 70% within the marsh fill/containment boundaries (328 acres created, 58 acres nourished), and by 42% within the ridge boundary, which is now 100% land (Figure 9). Because of the perimeter settlement within the in situ borrow areas, the project is just 14 acres short of the goal to create/nourish approximately 400 acres of marsh habitat, but achieves the goal of creating over 20 acres of land within the ridge boundary. It should be noted that the marsh platform was not fully vegetated by the time of the 2016 analysis, and it is possible that some mudflat areas classified as 'water' in 2016 may have subsequently become vegetated. Also, elevation data indicate that some of these 'water' areas may not be subtidal, but are actually areas where water is pooling on the surface of the marsh platform. Future land/water analyses are tentatively scheduled for 2024 (Year 9) and 2033 (Year 18), dependent on the scheduling of CRMS coast-wide flights which occur approximately every 3 years.

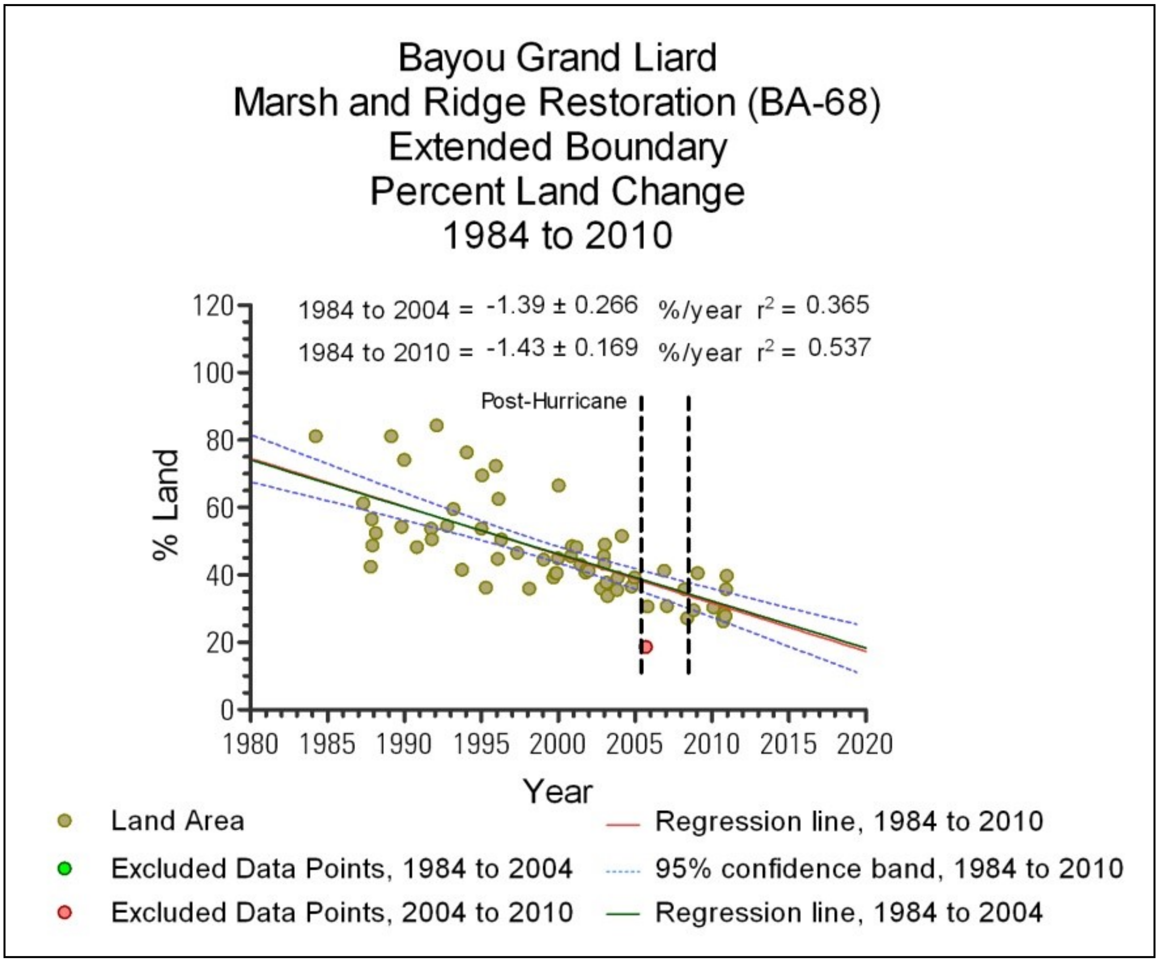

Figure 7. WVA land loss analysis for the BA-0068 project (NMFS 2011).

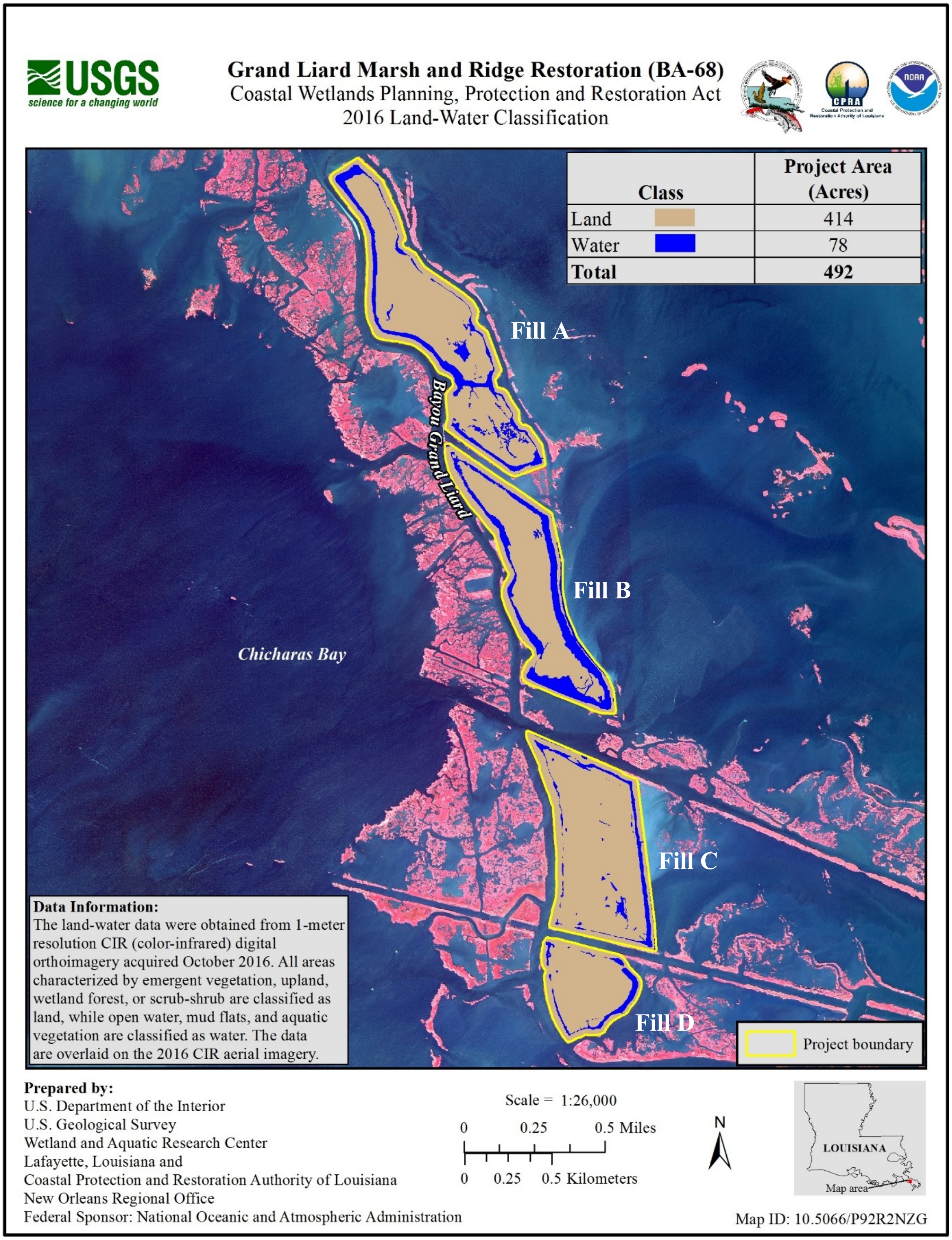

Figure 8. 2016 land/water analysis of the BA-0068 project area.

Table 3. Summary of 2016 land/water analysis data for the BA-0068 project (Year 1 Post-Construction).

	2016		
Area	Total Acreage	Land (acres)	% Land
Marsh Fill A	146	121	83%
Marsh Fill B	107	76	71%
Marsh Fill C	125	114	91%
Marsh Fill D	51	46	90%
Total Marsh Fill Areas	429	357	83%
Total Ridge	28	28	100%
Containment	35	29	83%
TOTAL Project	**492**	**414**	**84%**

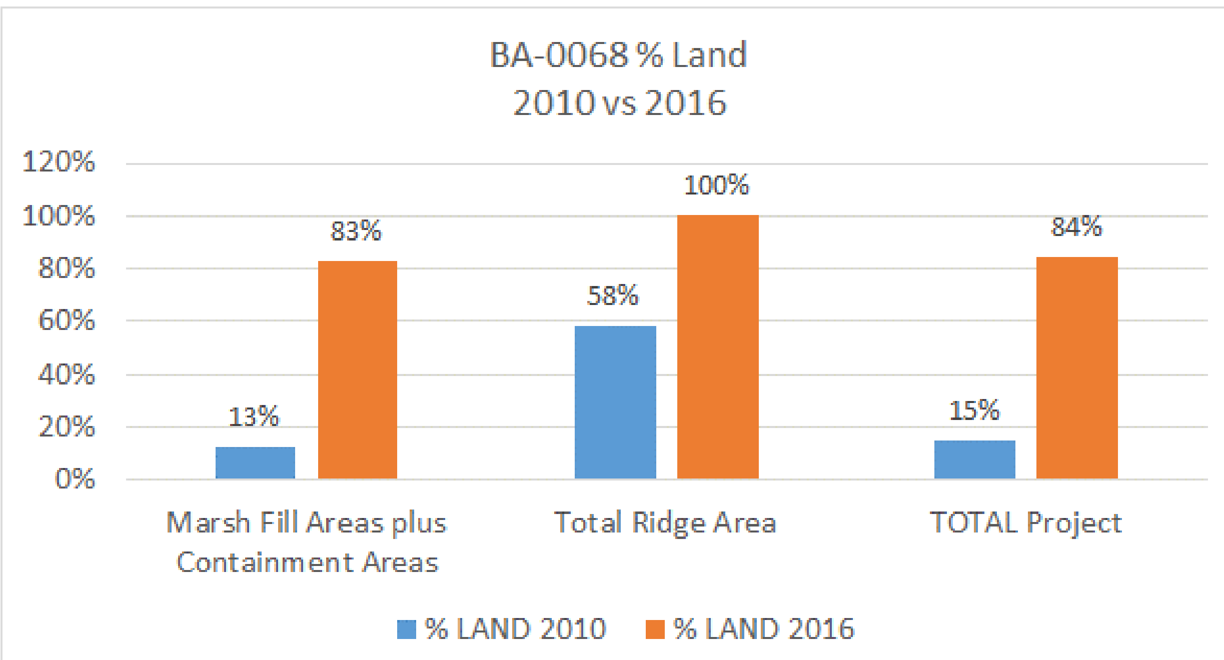

Figure 9. Estimated percent land within the BA-0068 project area and sub-areas in 2010 (Pre-Construction) and 2016 (Year 1 Post-Construction).

Elevation

Marsh Creation

During BA-0068 project design, target construction marsh fill elevations were determined through an investigation of several factors including existing healthy marsh elevation, tidal datum, relative sea level rise, the physical properties of the borrow material, and the bearing capacity of the foundation soils at the fill site (Fitzgerald et al. 2011). Optimally, the elevation of the marsh fill would be expected to settle to within the intertidal range within 3 to 4 years following construction and remain intertidal for the duration of the 20 year life of the project. All vertical elevations referenced during project design and construction were relative to an earlier geoid separation model (Geoid03, hereafter referred to as G03), and have been converted in this report to the updated geoid model (Geoid12B, hereafter referred to as G12B) using a factor of -0.827 ft, provided during the Year 3 (2018) survey (HydroTerra 2018).

At the time of the design survey in 2010, the highest healthy marsh in the surrounding area was determined to be +1.4 ft NAVD, G03 (+0.57 ft NAVD, G12B) (Sigma 2010). This elevation was generally targeted during the settlement analysis as the desired elevation of the marsh fill at Year 20 of the project life with the marsh fill nearing this elevation by approximately Year 10. The 2014 average marsh elevation of the nearest CRMS site to the project area, CRMS0163, was slightly lower than this target at +0.42 ft NAVD, G12B. Determination of local water levels is an essential factor in maximizing the ecological function of marsh creation projects, with the goal being to maximize the duration that the restored marsh will be intertidal during the 20-year project life. The CRMS station, CRMS0163, was used to determine the local tidal datum due to its proximity to the project site, and NOAA station #8761724 was used as the control station for the 19-year tidal epoch correlation, as described in Fitzgerald et al. 2011. Mean high water (MHW) and mean low water (MLW) at the time of project design (2011) were determined to be +1.35 and +0.30 ft NAVD G03 (+0.52 and -0.53 ft NAVD G12B). A relative sea level rise (RSLR) rate of 12.40 mm/yr (0.04 ft/yr) was applied to the tidal datum for the 20 year period as shown in Table 4. This RSLR rate was based on the Intergovernmental Panel on Climate Change (IPCC) eustatic seal level rise rate of 3.5 mm/year, plus an estimated local subsidence rate of 8.9 mm/yr (0.0292 ft/yr). Since the time of project design, various adjustments have been proposed to both the eustatic sea level rise rate and local subsidence rates which suggest the applied rate of 12.40 may be slightly overestimated; however, an observed water elevation change rate of 18.69 mm/yr (.06 ft/yr) at CRMS0163 over a 14 year period from 2007 to 2021 was even higher than the rate applied. Therefore, the RSLR assumptions proposed during design were retained.

It was determined during project design that a two lift construction sequence would allow the project to better meet the goals of achieving intertidal marsh within 3-4 years of construction and remaining above MLW for most of the design life. The target elevation of the second lift was not the same as the first lift, which is how previous two construction lift projects had been constructed. Borings in the marsh fill cells showed significant soil property variations and therefore fill cells were designed separately. The first construction lift was set to the same maximum fill height for all four cells; therefore, the height of the second construction lift varied from cell to cell depending on the resulting settlement predictions. The first construction lift was purposely set higher than the

Table 4. BA-0068 Tidal Datum adjusted for RSLR (ft NAVD, G03 and G12B).

Year	Project Life Year	MHW	MLW	MHW	MLW
		ft NAVD, GEOID03		ft NAVD, GEOID12B	
2010	-5	1.35	0.30	0.52	-0.53
2011	-4	1.39	0.34	0.56	-0.49
2012	-3	1.43	0.38	0.60	-0.45
2013	-2	1.47	0.42	0.64	-0.41
2014	-1	1.51	0.46	0.68	-0.37
2015	0	1.55	0.50	0.72	-0.33
2016	1	1.59	0.54	0.76	-0.29
2017	2	1.63	0.58	0.80	-0.25
2018	3	1.67	0.62	0.84	-0.21
2019	4	1.71	0.66	0.88	-0.17
2020	5	1.75	0.70	0.92	-0.13
2021	6	1.79	0.74	0.96	-0.09
2022	7	1.83	0.78	1.00	-0.05
2023	8	1.87	0.82	1.04	-0.01
2024	9	1.91	0.86	1.08	0.03
2025	10	1.95	0.90	1.12	0.07
2026	11	1.99	0.94	1.16	0.11
2027	12	2.03	0.98	1.20	0.15
2028	13	2.07	1.02	1.24	0.19
2029	14	2.11	1.06	1.28	0.23
2030	15	2.15	1.10	1.32	0.27
2031	16	2.19	1.14	1.36	0.31
2032	17	2.23	1.18	1.40	0.35
2033	18	2.27	1.22	1.44	0.39
2034	19	2.31	1.26	1.48	0.43
2035	20	2.34	1.30	1.51	0.47

Table 5. BA-0068 target marsh fill elevations (ft NAVD, G03 and G12B) for the Lift 1 and Lift 2 construction sequence.

Fill Cell	Lift 1 Min/Max	Lift 2 Min/Max	Lift 1 Min/Max	Lift 2 Min/Max
	ft NAVD, GEOID03		ft NAVD, GEOID12B	
A	+3.0/+3.5	+2.5/+3.0*	+2.2/+2.7	+1.7/+2.2*
B	+3.0/+3.5	+3.0/+3.5*	+2.2/+2.7	+2.2/+2.7*
C	+3.0/+3.5	+2.3/+2.8	+2.2/+2.7	+1.5/+2.0
D	+3.0/+3.5	+2.5/+3.0	+2.2/+2.7	+1.7/+2.2

*Maximum fill height of Fill Cell A was increased to +3.5 ft NAVD, G03 (+2.7 ft G12B) and maximum fill height of Fill Cell B was decreased to +3.0 ft NAVD, G03 (+2.2 ft G12B) during construction.

second lift to increase the primary initial consolidation of the underlying soil. This would reduce the amount of consolidation settlement in the second construction lift and allow the marsh fill height to reach intertidal range sooner and remain there for the duration of the project life. This fill configuration is also beneficial for the earthen ridge and containment dikes as they can be constructed at the same design fill height for the first construction lift, rather than having them change with each fill cell design. The target fill heights selected for the two-lift construction sequence are shown in Table 5 in both geoids for the four separate fill cells; however, for ease of reporting, all elevations will hereafter be reported in ft NAVD88 relative to the G12B model only.

The first and second lifts were designed to be constructed in the same sequential order for the four fill cells, and the fill times between lifts were based on the production rates typically experienced on similar dredging projects at the time with roughly 25:75 sediment to water ratio. The estimated fill time, or waiting period, between lifts was used to calculate the fill height for the second lift; therefore, no waiting time was specified in the contract. During construction, however, the contractor mobilized a new dredge that significantly outperformed previous production rates observed on other CPRA projects at that time, and was able to pump fill material in higher quantities and concentrations than predicted. In order to allow more settlement time between fill areas, the CPRA temporarily suspended dredging for 60 days and added 60 days to the contract time. Second lifts, however, had already occurred on Areas C and D before work was suspended. During the 60-day downtime, the CPRA was able to re-evaluate the settlement data for each fill cell and determine if any adjustments to the fill heights of the second lifts were necessary, or if third lifts would be necessary for Cells C and D. It was determined that the maximum fill height for Cell A would be increased by +0.5 ft and for Cell B would be decreased by -0.5 ft. Cells C and D remained at the same target fill heights and required a third lift.

Mean elevations within the fill areas were determined from elevation grid models (Figure 10) for each of the survey years, and grid models were compared to produce elevation change models between the survey years (Figure 11). The pre-construction elevation change model (2010 to 2014) showed only minor changes in elevation within the project area in the immediate pre-construction period. Mean elevation change from 2010 to 2014 ranged from -0.4 ft in Area B to +0.6 ft in Area C, and mean change overall was +0.03 ft (Figure 11). The mean elevation immediately before construction (2014) ranged from -2.3 ft in Area B to -0.8 ft in Area C (Figures 10 and 12).

As a result of BA-68 construction in 2015, the overall mean elevation increased by +3.8 ft within the fill cells, with the increase ranging from +3.3 ft in Area B to +4.2 in Area C. Despite having the greatest increase in elevation and the highest target elevation, Area B had the lowest as-built elevation following construction of +1.8 ft (Figures 10 and 12). As-built elevations within the other fill cells were +2.2 ft in Area A and +2.4 ft in Areas C and D. Sediment volume increased by approximately 2,588,110 CY (1,978,752 m^3) within the fill areas, which includes a 184,525 CY adjustment to account for the percentage of area missing from the grid model due to the limitations of the survey extents (Figure 13). The dredged quantity reported in the BA-0068 project completion report (AECOM 2016) for the four fill areas was 9% higher [2,834,000 CY (2,166,748 m^3)] presumably due to immediate post-fill compaction that may have occurred before the as-built survey, as well as the difference in calculation methods. Volume losses due to settlement and compaction were observed in the years following construction, with a loss of 788,087 CY (602,536

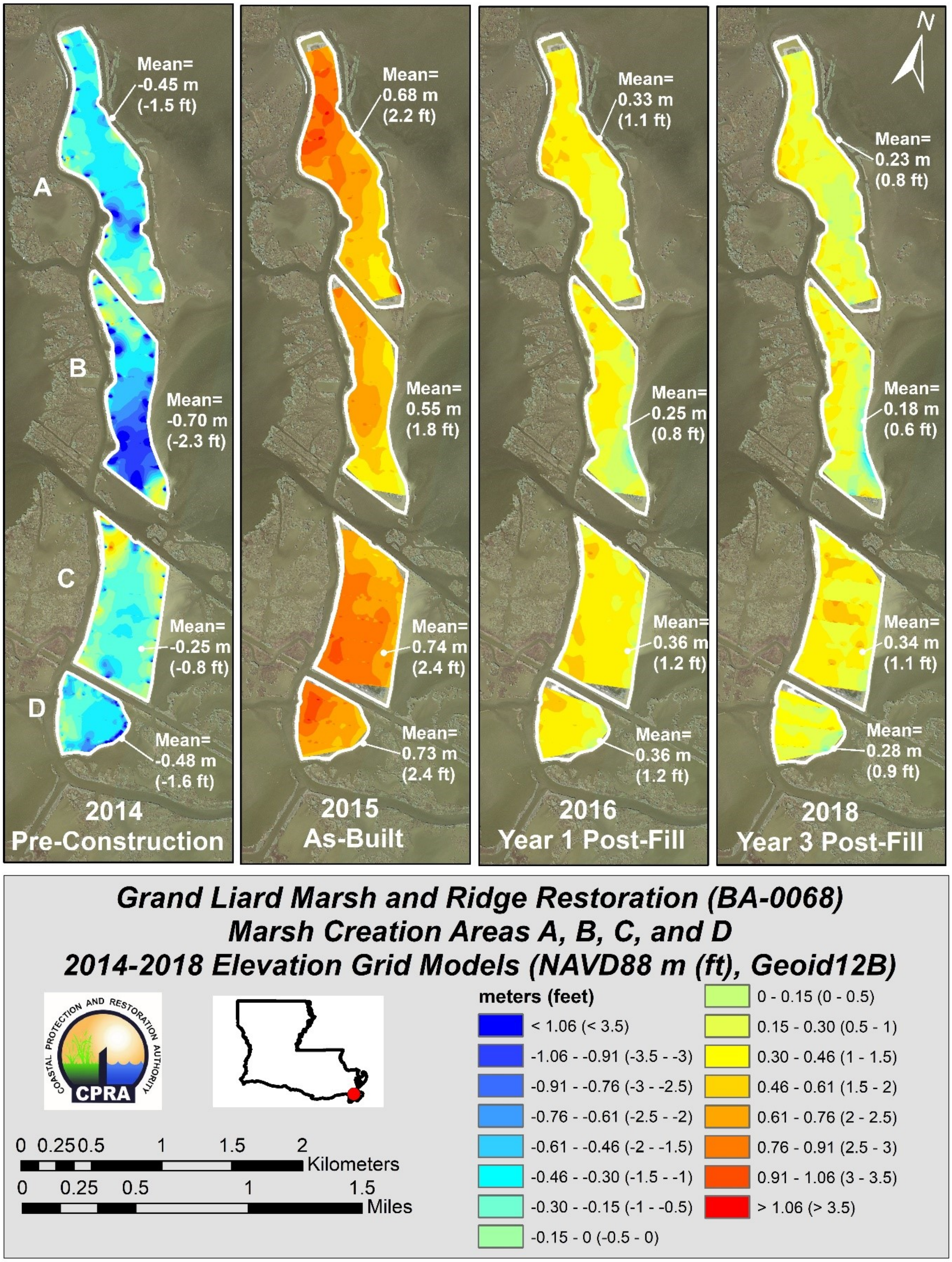

Figure 10. Elevation grid models for the four marsh fill areas associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project in 2014, 2015, 2016, and 2018.

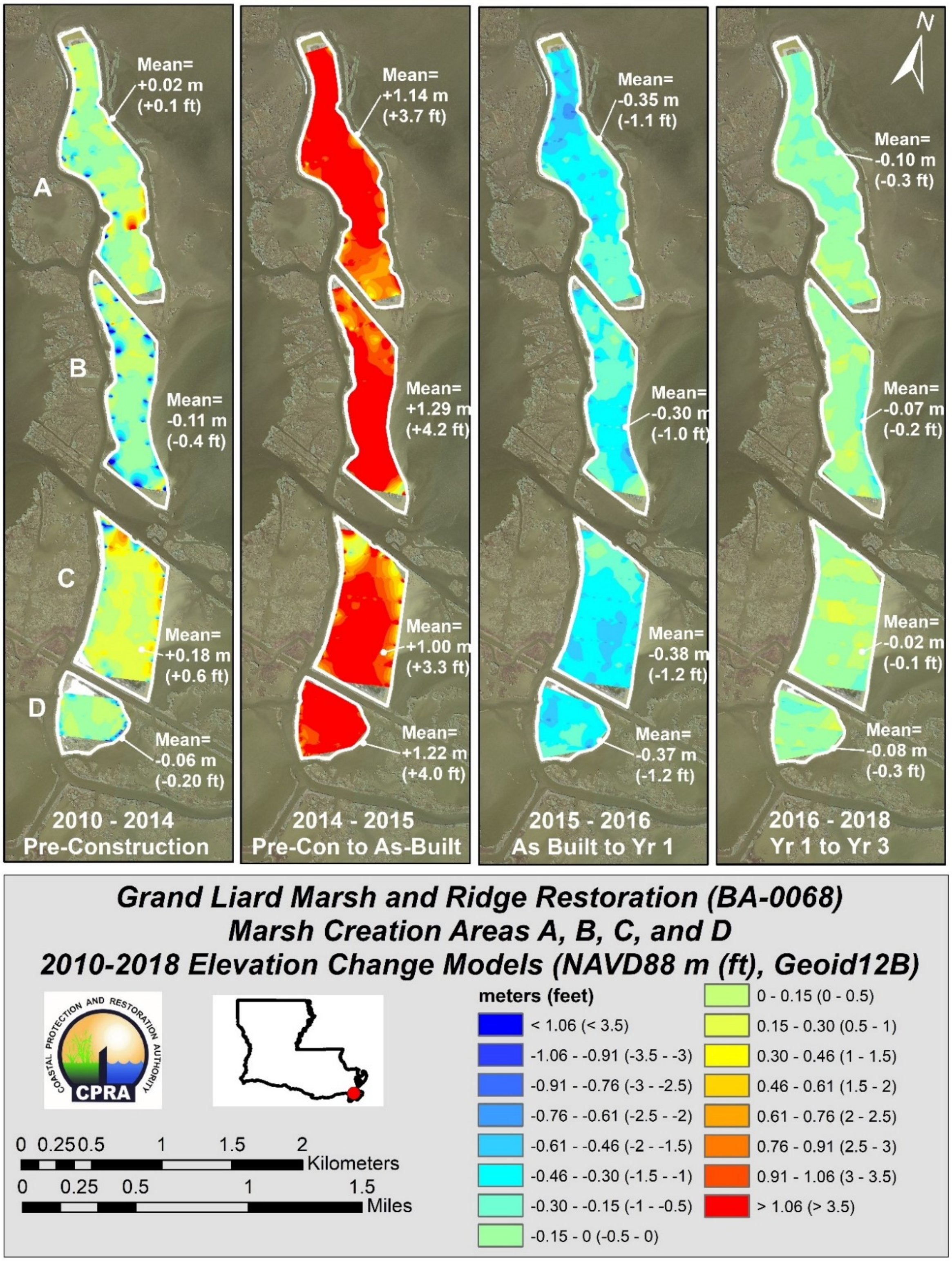

Figure 11. Elevation change models for the four marsh fill areas associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project for four time periods: 2010 to 2014, 2014 to 2015, 2015 to 2016, and 2016 to 2018.

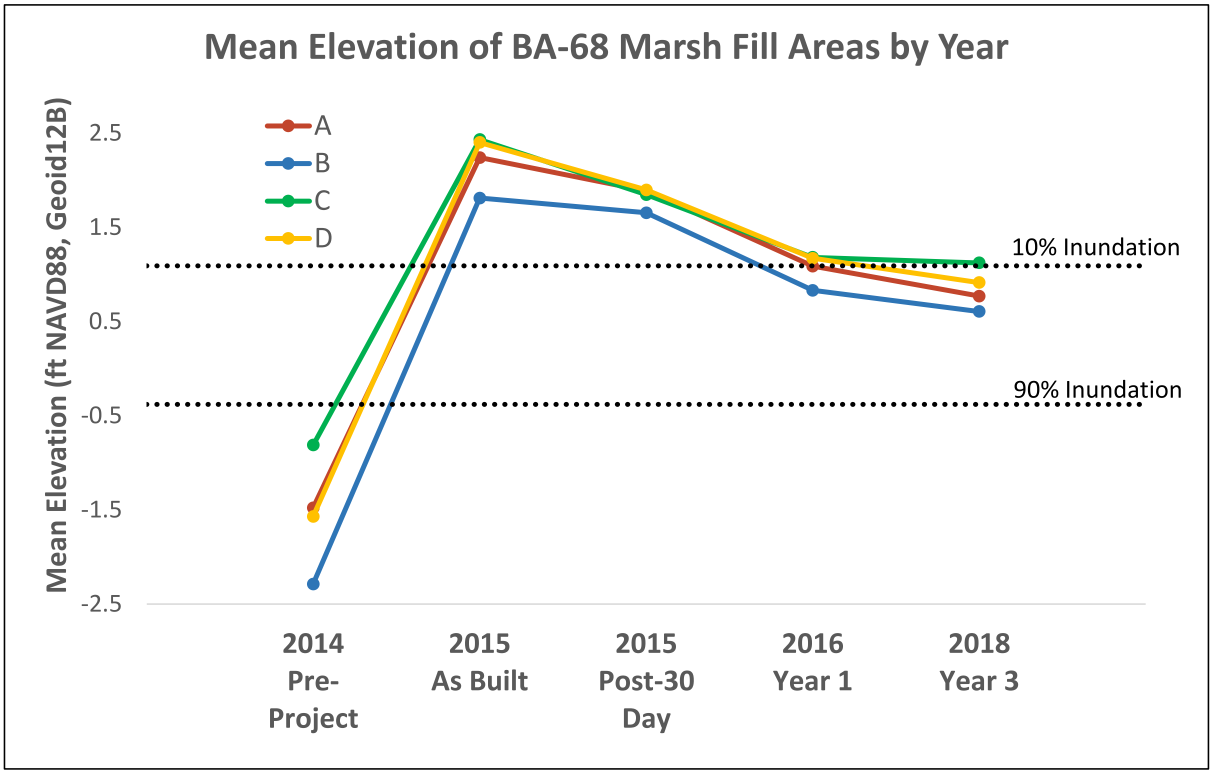

Figure 12. Summary of changes in mean elevation for the four marsh fill areas associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project from 2014 to 2018.

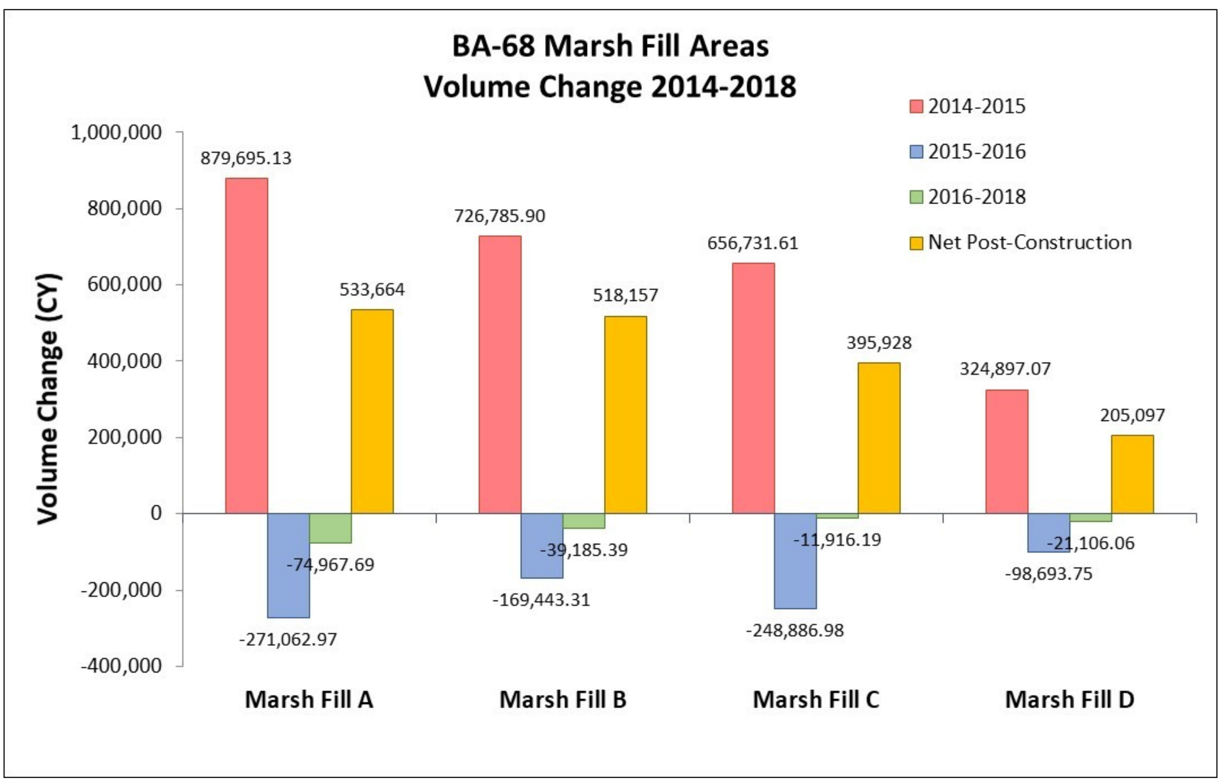

Figure 13. Volume change (CY) over time within the BA-0068 fill areas.

m^3) one year after construction and a smaller loss of 147,175 CY (112,523 m^3) between one and three years after construction. Total net volume change from construction to Year 5 is estimated at +1,652,847 CY (1,263,692 m^3), which corresponds to approximately 64% of the in-place construction volume remaining.

One year after construction, overall mean elevation decreased by -1.1 ft within the fill areas, with settlement of -1.0 ft in Area B, -1.1 ft in Area A, and -1.2 ft in Areas C and D. The percentage of this settlement occurring within the first 30 days following construction was 31% (-0.4 ft) within Area A, 16% (-0.2 ft) within Area B, 47% (-0.6 ft) within Area C, and 41% (-0.5 ft) within Area D (Figure 12). Between 1 and 3 years after construction, there was an additional settlement of -0.1 ft in Area C, -0.2 ft in Area B, and -0.3 ft in Areas A and D. The mean elevation within the fill areas at three years after construction was lowest in Area B at +0.6 ft, followed by Area A at +0.8 ft, Area D at +0.9 ft, and Area C at +1.1 ft.

The 20-year predicted time-rate settlement curve for each fill cell was based on the maximum target fill height of the second construction lift. This predicted curve is plotted along with the observed mean elevation through post-construction Year 3 for each of the four fill areas in Appendix C. The design goal was to achieve an intertidal elevation between MHW and MLW as soon as possible following construction, and to remain within that range for the duration of the project life with a RSLR rate of 12.40 mm/yr (0.04 ft/yr) applied as indicated in Table 4. The 'healthy marsh' elevation identified during design of +0.6 ft was used as a general target for the Year 10 elevation, with very little additional settlement expected between Years 10 and 20. The 10%-90% inundation range is also projected on the settlement graphs because the percentage of maximum productivity of saline marshes has been estimated at 60% or greater within this inundation range if salinities are optimal (Visser et al. 2004), and the marsh platform would be expected to reach the 10% inundation level before the MHW level.

The observed elevations at Year +3 were higher than the design target elevation for Year +10 (+0.6 ft) in all fill areas except for Area B, which had already reached the Year +10 target level by Year +3. The observed settlement within Area A was the most similar to the predicted curve (Appendix C-1). As-built fill height was only 0.04 ft higher than the design target and was 0.1 ft higher than predicted at Year 3. The mean elevation at Year 3 (+0.8 ft) is just below MHW level and would be expected to remain within the target range for healthy marsh for the duration of the 20-year project life. Observed settlement within Area B was below the predicted curve (Appendix C-2). This fill area had the lowest mean elevation before construction (-2.3 ft) and the highest fill target of +2.7 ft; however, this target was reduced by half a foot to +2.2 ft before the second lift was conducted and the mean as-built elevation of +1.8 ft was below this reduced target. Settlement by Year 1, however, was 0.7 ft lower than predicted, likely resulting from reduced compaction of underlying sediments due to the lower fill volume, and the resulting elevation by Year 3 of +0.6 ft was only 0.3 ft lower than predicted. An additional factor affecting elevations in Area B is that an area of the containment dike on the eastern side, which is exposed to open water and higher wave energies, eroded not long after construction. As a result, an area of erosive scour has developed along the eastern side of Area B (Figure 10). Marsh at the mean elevation of Area B would be expected to be flooded between 30-40% of the time and is within the range for healthy marsh;

however, the mean elevation by Year 20 will likely be below predicted MLW and may be below the 90% flooding level.

Observed mean elevation within Area C was above the predicted curve; however, the total amount of settlement by Year 3 (-1.2 ft) was the same as predicted (Appendix C-3). Mean as-built fill elevation was 0.4 ft above the maximum fill target of +2.0 ft following the third lift, and the design curve was based on only two lifts. Although the overall amount of settlement was the same as predicted by Year 3, it was greater than expected within the first year and lower than expected between Years 1 and 3, and therefore did not follow the predicted curve. The mean elevation at Year 3 was just approaching the 10% inundation level and mean elevation by Year 20 will be expected to remain within the optimum range for the duration of the 20-year life. Despite also receiving a third lift, the observed settlement within Area D was similar to the predicted curve (Appendix C-4). The mean as-built fill elevation was 0.2 ft above the fill target and the Year 3 mean elevation was 0.1 ft higher than predicted. Marsh at the Year 3 elevation would be expected to be flooded between 10-20% of the time, and the elevation by Year 20 is expected to still be within the optimum range.

To visualize the changes in intertidal area within the marsh fill areas over time, the acreage within the 10%-90% inundation range was calculated for the entire marsh creation area (Figure 14) and for each fill area separately (Figure 15). Immediately before construction (2014), only 52 acres (12%) of the combined Fill Areas were within the intertidal range, and 369 acres (86%) were subtidal, i.e. inundation more than 90% of the time. All Fill Areas were 100% supratidal immediately following construction in 2015, except for Area B which had 4 intertidal acres (4%) following construction. By 2016 (Year +1), approximately 149 acres (37%) within the combined fill areas had settled to intertidal range, which increased to 245 intertidal acres (62%) by 2018 (Year +3). All four fill areas showed a progression toward increased intertidal area by Year +3, and only Area B contained subtidal acreage (7 acres) at Year +3. It should be noted that elevations within the supratidal range (inundation <10% of the time) is still supportive of productive *Spartina alterniflora* marsh and lower flooding regimes (0-20%) have been associated with higher growth rates and increased biomass for this species (Visser and Sandy 2009). It is evident that these higher elevation areas had also become significantly vegetated by 2016 (Year +1) since the acreage of vegetated land from the 2016 land/water analysis was similar to the combined supratidal/intertidal acreage in 2016 (Figure 16). Therefore, it would be preferable for marsh elevations within the fill areas to be at or above the desired target range in order to remain within the ideal flooding range for the duration of the project life, and Fill Areas A, C, and D are still performing well despite being slightly above the target range at Year +3. Fill Area B is currently well-vegetated and the Year +3 elevation was within the ideal flooding range; however, since the current elevation is lower within the tidal prism, it may be at risk for falling below this range by the end of the project life.

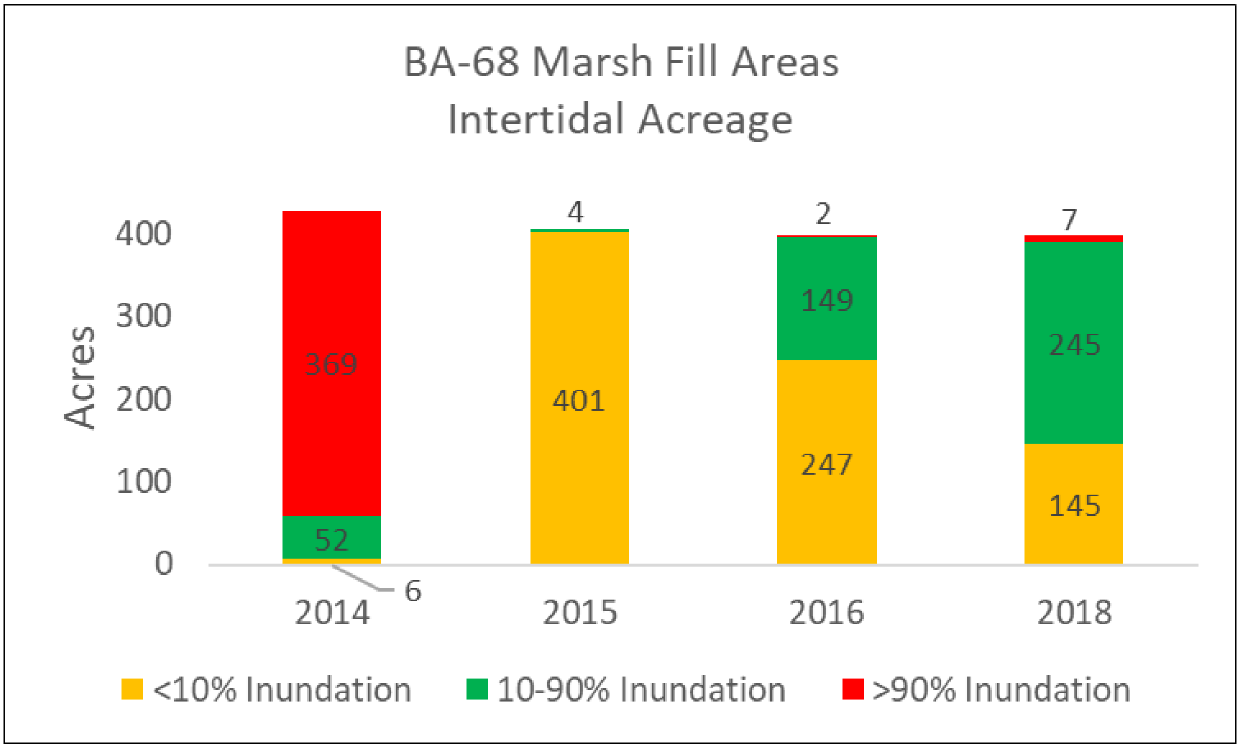

Figure 14. Change in intertidal acreage over time within the BA-0068 combined marsh fill areas.

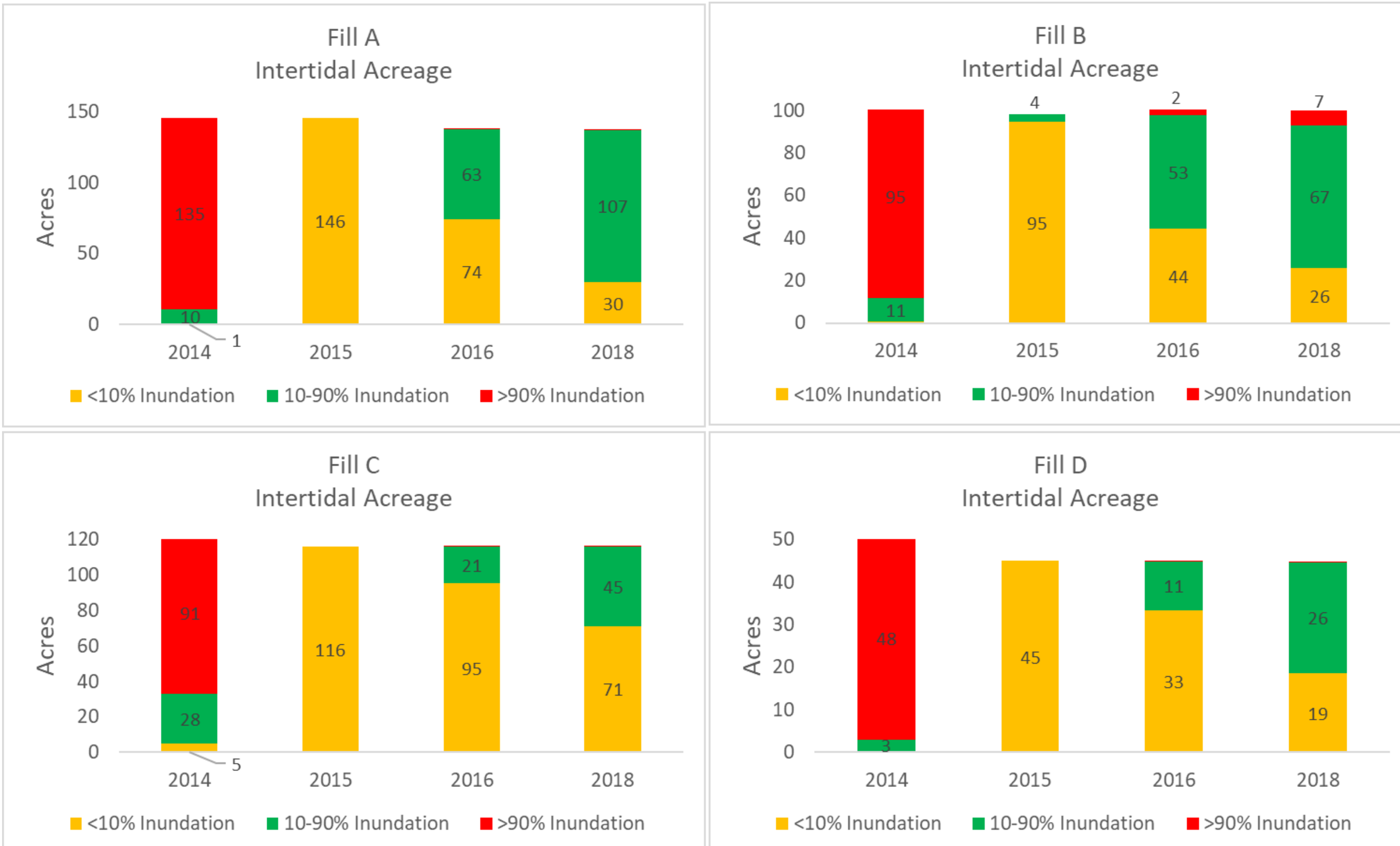

Figure 15. Change in intertidal acreage over time within each of the BA-0068 marsh fill areas.

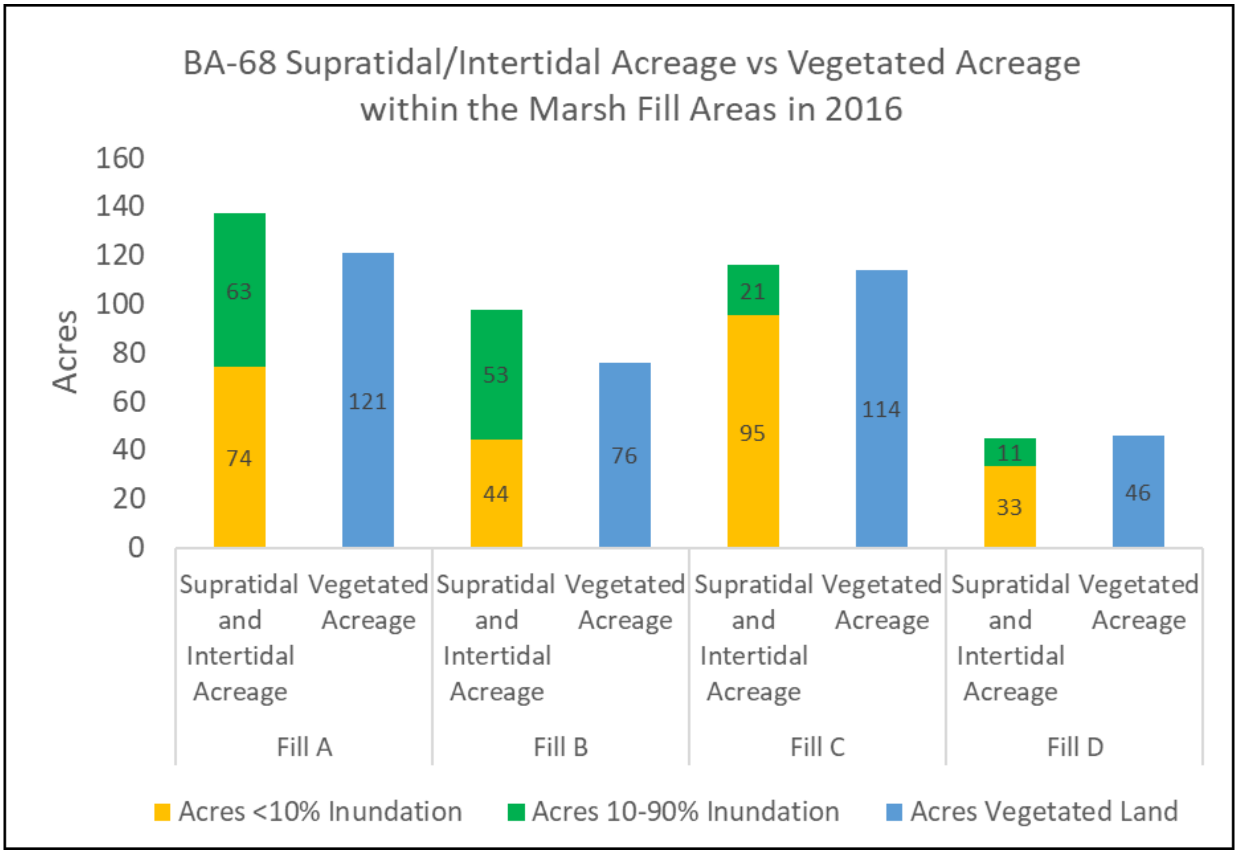

Figure 16. BA-68 supratidal/intertidal acreage vs vegetated acreage within the marsh fill areas in 2016 (one year post-construction).

Ridge Creation

During BA-0068 project construction, a total of 16,769 linear feet (~28 acres) of earthen ridge were constructed using material primarily sourced from Bayou Grand Liard and to a lesser extent from within the marsh creation areas. The ridge was constructed to a design template of +4.5 ft NAVD88 G03 (+3.7 ft NAVD88 G12B) minimum crest height, 20-foot crest width, and side slopes of 7H:1V. The proposed ridge design was guided by limitations in geotechnical conditions associated with the borrow material and structure stability; however, surveys of nearby elevated banklines showed elevations ranging from +3.5 ft to +6 ft (G03) (NMFS 2011). During design, settlement analyses were initially conducted with a target crown height of +5.5 ft NAVD88 G03 (+4.7 ft NAVD88 G12B), but the target crown height was later lowered to +5.0 ft G03 as a cost-saving measure because the adjacent marsh fill height had been lowered by half a foot (Fitzgerald et al. 2011). Based on the final design, the ridge was expected to settle to approximately +3.0 ft NAVD88 G03 (+2.2 ft NAVD88 G12B) by Year 10 and remain near that elevation for the duration of the 20-year life (NMFS 2011). For ease of reporting, all elevations will hereafter be reported in ft NAVD88 relative to the G12B model only.

Mean elevations within the four ridge creation areas were determined from elevation grid models interpolated from the 2015, 2016, and 2018 topographic surveys (Figures 17-20), and survey points taken along the ridge centerline were averaged to determine the mean crown elevation for each of the ridge areas. Resulting mean ridge elevations through post-construction Year 3 are summarized in Figure 21. The as-built survey (2015) showed that mean crown height of the four ridge areas was 1.0 ft or more above the minimum target crown height of +3.7 ft, with the mean crown elevation ranging from +4.7 ft in Area B to +5.3 ft in Area C. Mean elevation of the total ridge footprint ranged from +3.0 ft in Area B to +3.7 ft in Area A. By Year 3, mean crown elevation settled by a mean of 1.1 ft for all ridges combined to ~4.0 ft (Table 6), with 0.7 ft of settlement by Year 1 and 0.4 ft of additional settlement by Year 3. Resulting mean crown elevations ranged from +3.8 ft in Areas B and D to +4.3 ft in Area C. Observed settlement of the crown was highest within Area D during both time periods (As Built to Year 1 and Year 1 to Year 3).

The predicted settlement curve for the original +4.7 ft target fill height design is plotted along with the observed mean crown elevation through post-construction Year 3 for each of the four fill areas in Appendix C-5. The as-built crown elevation of the ridge in Area B (+4.7 ft) was the same as the target fill height used for the predicted curve, while the fill elevation of the other ridge areas were slightly higher. The comparison shows that observed mean crown elevations within the four ridge areas at Year +3 were 1.0-1.5 ft higher than the predicted elevation for Year +3 (+2.8 ft) based on a +4.7' fill height. Almost 2 feet of crown settlement had been predicted by Year +3, while only 1.1 feet of settlement was observed for the combined ridge areas. This lower than predicted settlement rate observed within the ridge creation areas is likely due to additional 'dressing' of the ridges which occurred after the as-built process surveys of the ridge were taken and while marsh fill placement was occurring. Although ridge construction was considered complete as of 3/24/2015 (AECOM Technology Services 2016), daily contractor notes indicate that marsh buggies continued to reshape and add material to the ridge areas to meet project specifications through August 2015. Therefore, as initial fill settlement occurred along the ridge areas, crews made up for these losses by adding new material to meet design specs over several months. This significantly reduced the resulting observed settlement rate of the fill material, but likely increased the below-fill settlement due to the weight of additional material.

Before construction, seven settlement plates were installed along the ridge area to monitor vertical consolidation of the underlying sediments during construction (Figures 17-20). Below fill settlement observed during construction was reported to be much higher in Areas C and D (2.2 and 2.8 ft) than in Areas A and B (0.6 and 1.2 ft) (AECOM Technology Services 2016); however, it appears that the construction settlement reported for Areas A and B does not include an immediate pre-fill elevation reading which would have captured the initial (greatest) period of settlement immediately following fill placement. The settlement plates were also measured in Years +1 and +3 to quantify the amount of below fill settlement occurring during the post-construction period. The observed below fill settlement was subtracted from the total crown settlement to obtain an assumed settlement within the fill material. The quantity of below fill settlement is shown in Table 6 and compared graphically to the within fill settlement in Figure 22. Results showed that mean below fill settlement of the ridge areas accounted for 50% of observed settlement by Year 1 and 89% of the observed settlement between Years 1 and 3. For the total post-construction period, below fill settlement accounted for a majority of the observed settlement in all ridge areas except for Area A; however, the placement of the settlement plate in Area A is off center from the ridge crown which may have resulted in reduced below-fill compaction due to lower weight of fill. In general, the relatively low quantity of within-fill settlement observed in the immediate years following construction is likely due to the redressing of the ridge areas which replaced lost quantities as initial settlement occurred, thereby reducing the overall amount of settlement observed at Year +1.

Although the observed settlement of the ridge was lower than expected by Year +3, this is not a detriment to ridge function and the resulting higher elevation of the ridge would be expected to increase the longevity of the life of the ridge and increase its resilience to storm events. Acreages calculated within the 1-foot elevation intervals shown in Figures 17-20 for the combined ridge areas indicate a highly stable ridge with very little changes between elevation intervals by Year +3 (Figure 23). Since the Year +3 (2018) survey, the project area was impacted by two major storm events with storm surge elevations high enough to overtop the constructed ridge. Hurricane Zeta made landfall on October 28, 2020 near Cocodrie, Louisiana with an intensity of 100 kt (115 mph) and produced storm surge inundation of 6 to 10 ft AGL (above ground level) in areas to the west of the Mississippi River Levee in Plaquemines Parish (Blake et al. 2021). A storm surge of about 5.2 ft above normal tide levels was measured at Joshua's Marina in Buras near the project area, which was verified by high water levels recorded at nearby CRMS sites (CRMS0181=5.6 ft, CRMS0163=4.5 ft). One year later, Hurricane Ida made landfall near Port Fourchon on August 29, 2021 with maximum sustained winds of 130 kt (150 mph). During that storm, CRMS0163 showed a high water reading of 4.8 feet. There was clear evidence during post-storm assessments (wrack deposition, scour, missing plants, etc.) that the ridge was overtopped from the west, primarily during passage of Hurricane Zeta. Although these storm events appear to have accelerated erosion of the crown and narrowing of the ridge profile in some areas, the higher than anticipated ridge elevation likely provided additional resiliency to these events. Frequency of future storm events will have some impact on the ridge plantings with regard to salinity exposure, which is decreased with greater ridge height. Hackberry seedling have been shown to survive temporary exposure to salinities greater than 5 ppt provided the soils are subsequently flushed with freshwater, but they are unlikely to survive frequent, repeated exposure to such conditions (Williams et al. 1998, Williams et al. 1999). In addition to Hurricanes Zeta and Ida, the only other instances where water levels at CRMS0163 reached heights enough to overtop the level of the currently constructed ridge (since monitoring began in 2007) was during Hurricane Gustav in 2008 and Hurricane Isaac in 2012. The next elevation survey is scheduled to occur in 2025, which will quantify changes in elevation by Year +10 of the project life including impacts from the 2020/2021 storms; however, on the current trajectory, the ridge is expected to remain above marsh elevation beyond the duration of the 20-year project life.

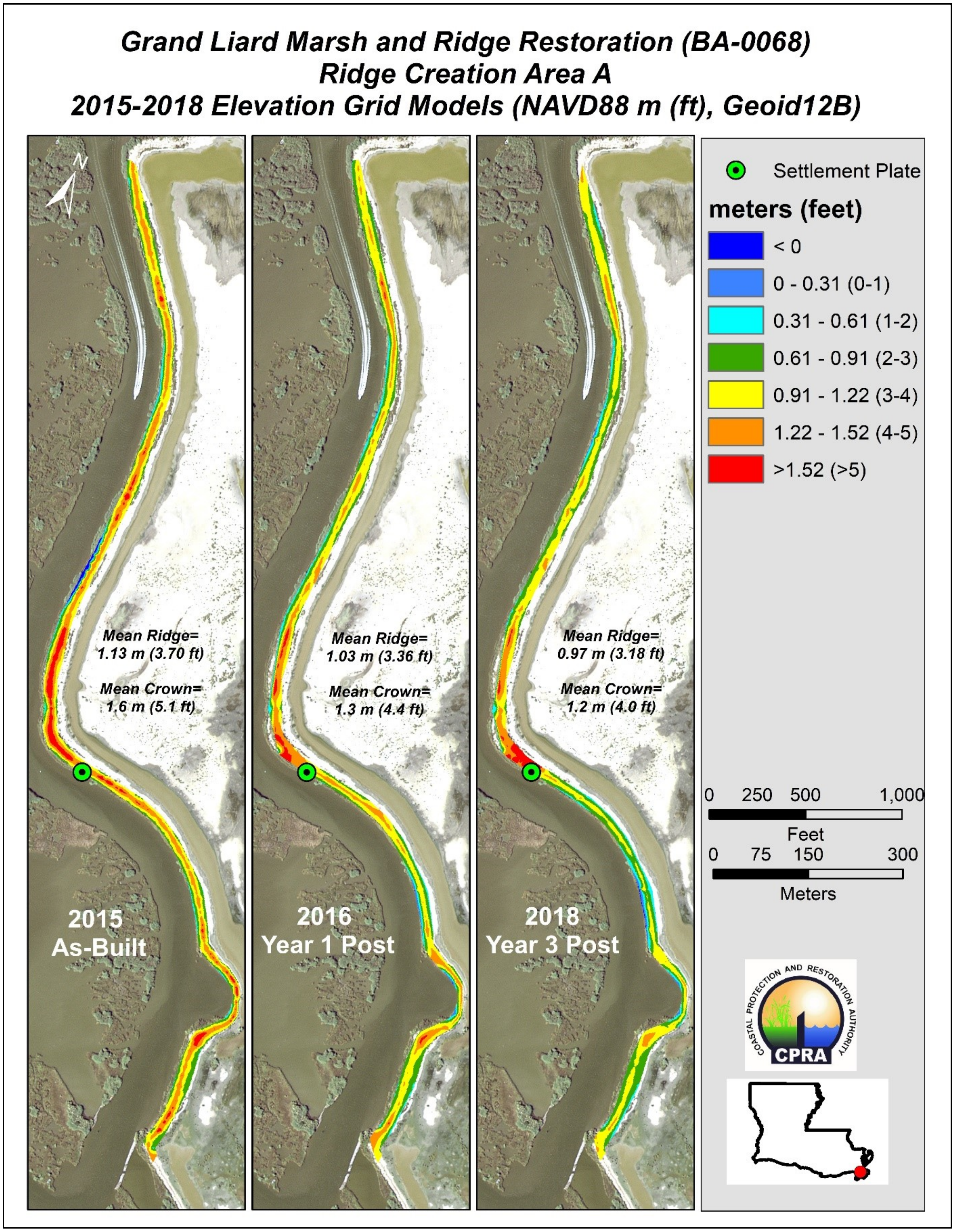

Figure 17. Elevation grid models of Ridge Creation Area A associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project in 2015, 2016, and 2018.

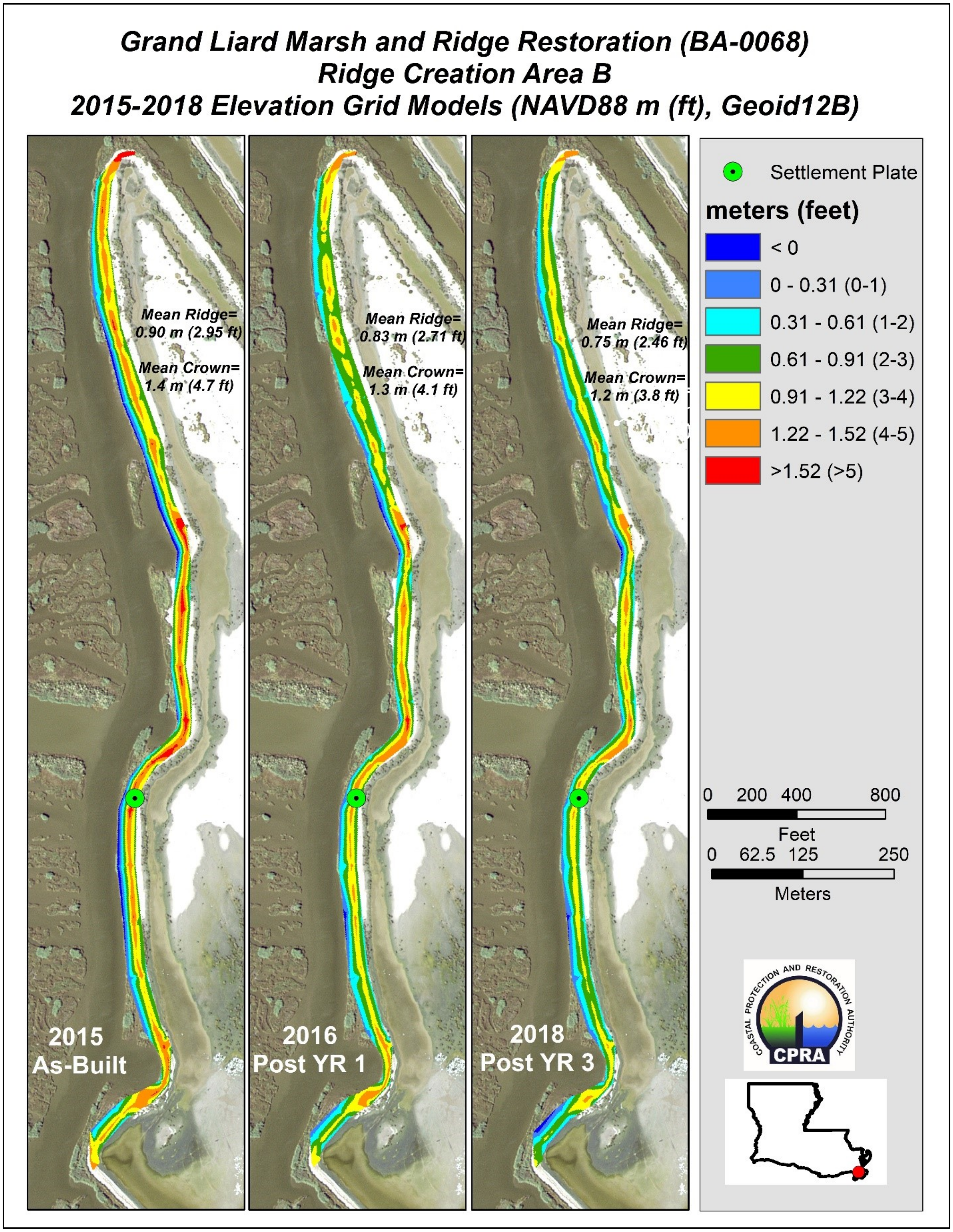

Figure 18. Elevation grid models of Ridge Creation Area B associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project in 2015, 2016, and 2018.

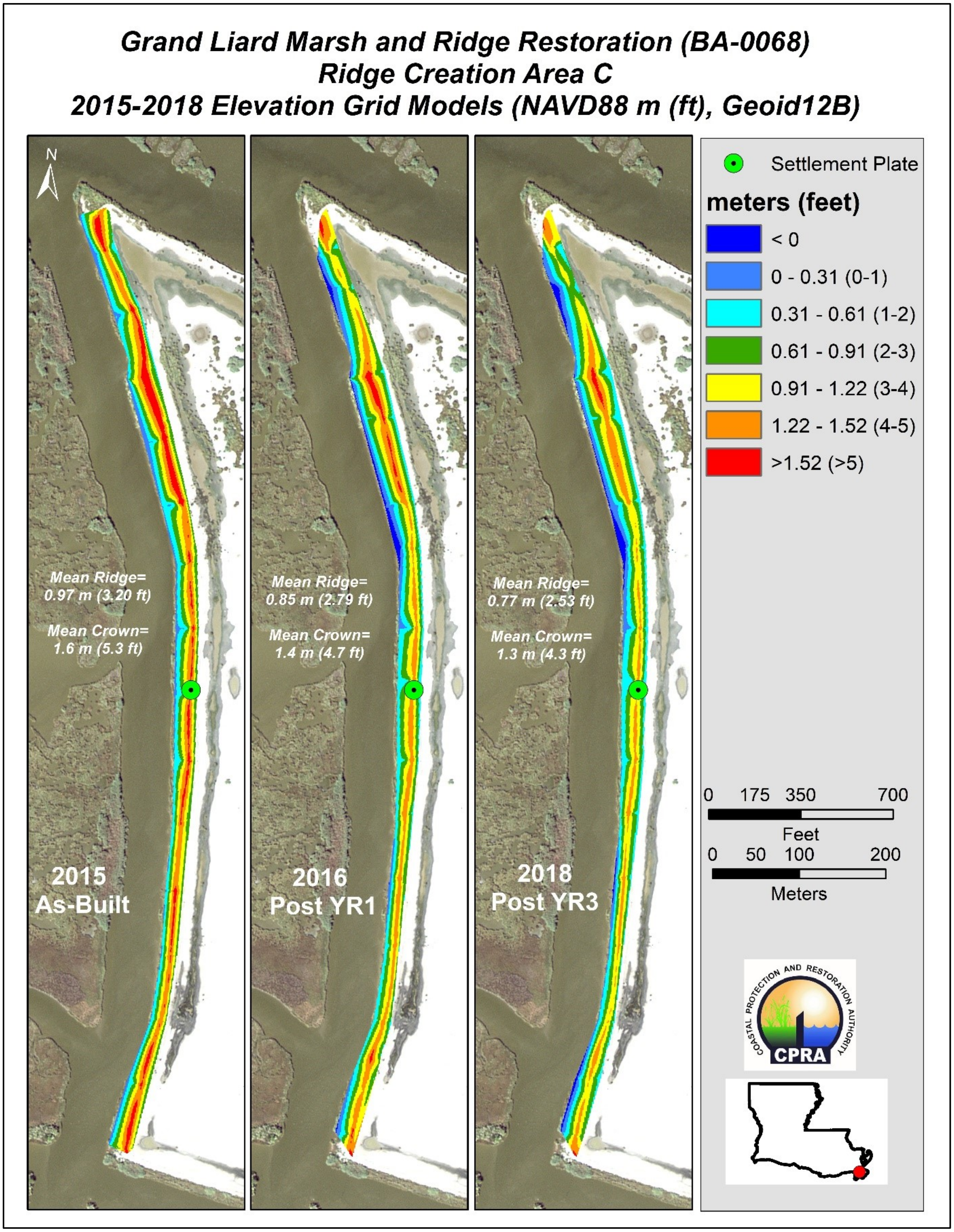

Figure 19. Elevation grid models of Ridge Creation Area C associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project in 2015, 2016, and 2018.

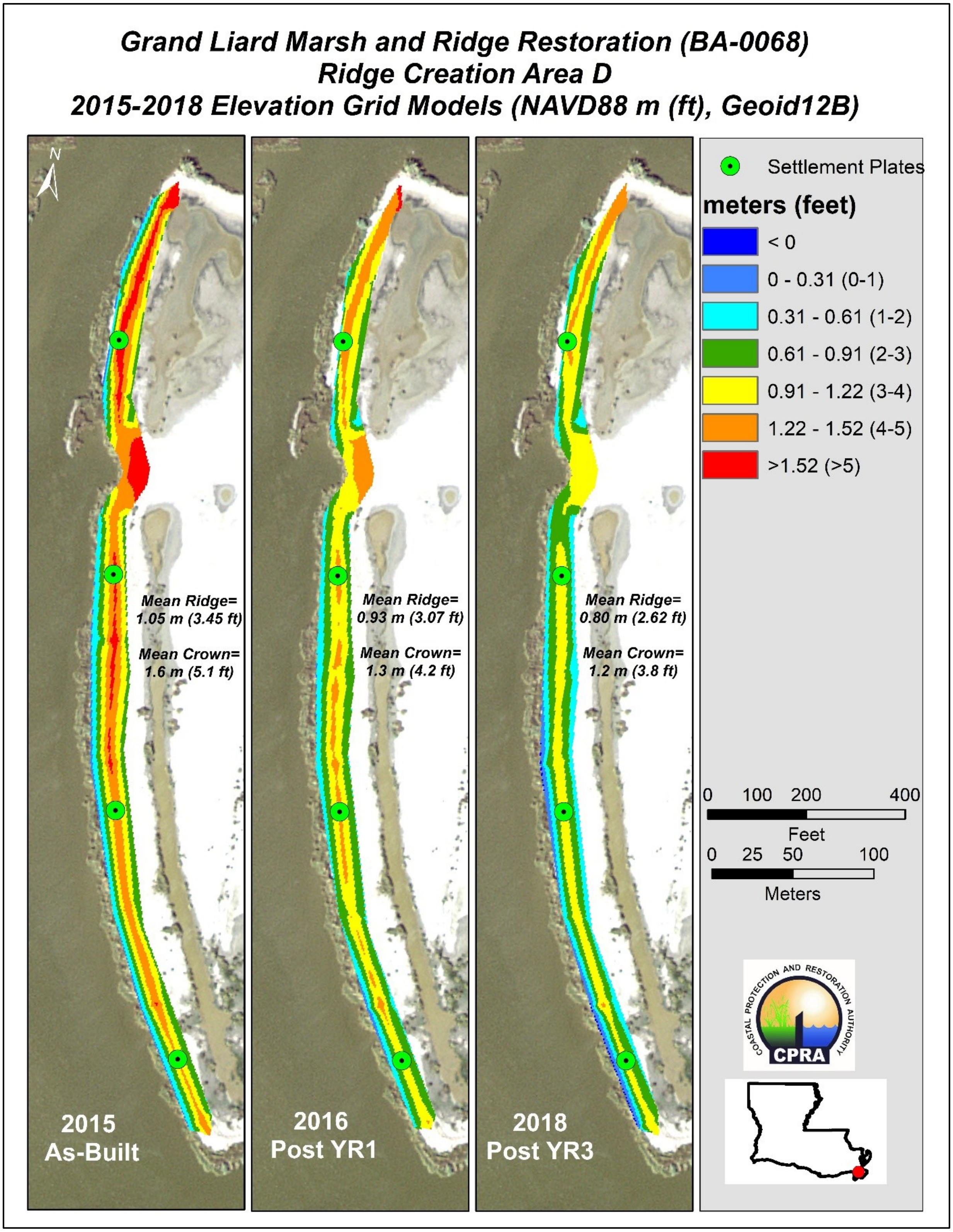

Figure 20. Elevation grid models of Ridge Creation Area D associated with the Grand Liard Marsh and Ridge Restoration (BA-0068) project in 2015, 2016, and 2018.

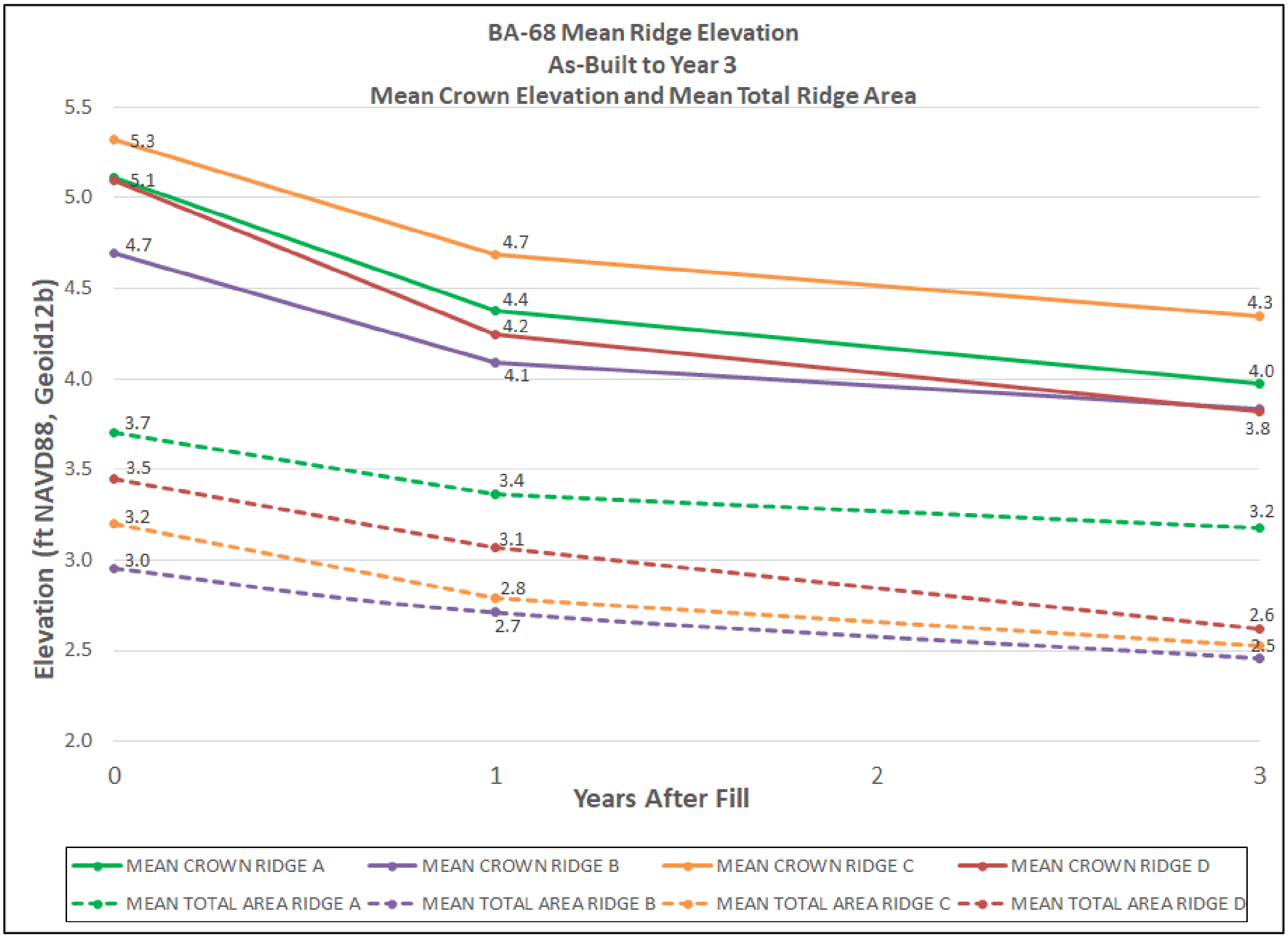

Figure 21. Mean elevation of the ridge crown and within the total ridge footprint of four ridge creation areas associated with the BA-0068 project in 2015, 2016, and 2018.

Table 6. Summary of below fill and crown settlement (ft) of the BA-68 ridge areas from as-built condition (2015) to Year 3 (2018).

RIDGE SETTLEMENT (FT)							
	As Built to Year 1		Year 1 to Year 3		TOTAL SETTLEMENT		
	Below Fill	Ridge Crown	Below Fill	Ridge Crown	Below Fill	Ridge Crown	% Below Fill
RIDGE A	-0.1	-0.7	-0.3	-0.4	-0.4	-1.1	38
RIDGE B	-0.4	-0.6	-0.3	-0.3	-0.7	-0.9	78
RIDGE C	-0.3	-0.6	-0.3	-0.3	-0.6	-1.0	61
RIDGE D	-0.6	-0.9	-0.4	-0.4	-1.0	-1.3	80
MEAN	**-0.4**	**-0.7**	**-0.3**	**-0.4**	**-0.7**	**-1.1**	**64**

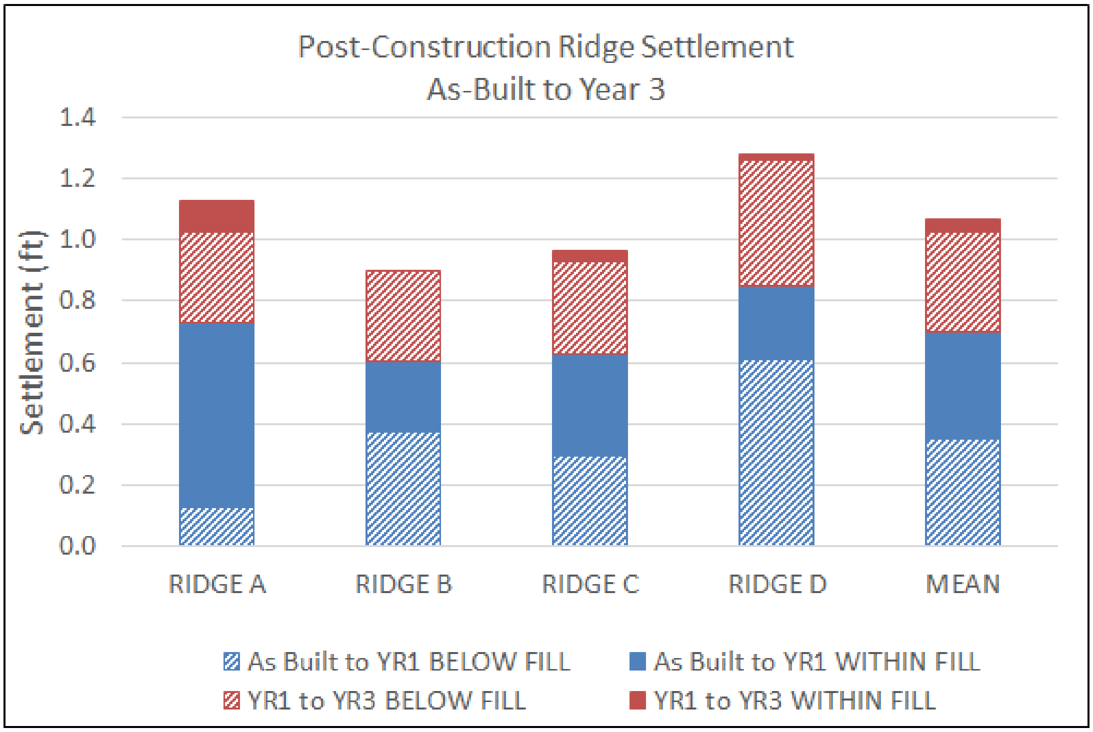

Figure 22. Below-fill and within-fill settlement from 'as-built' to Year 1 (blue), and from Year 1 to Year 3 (red).

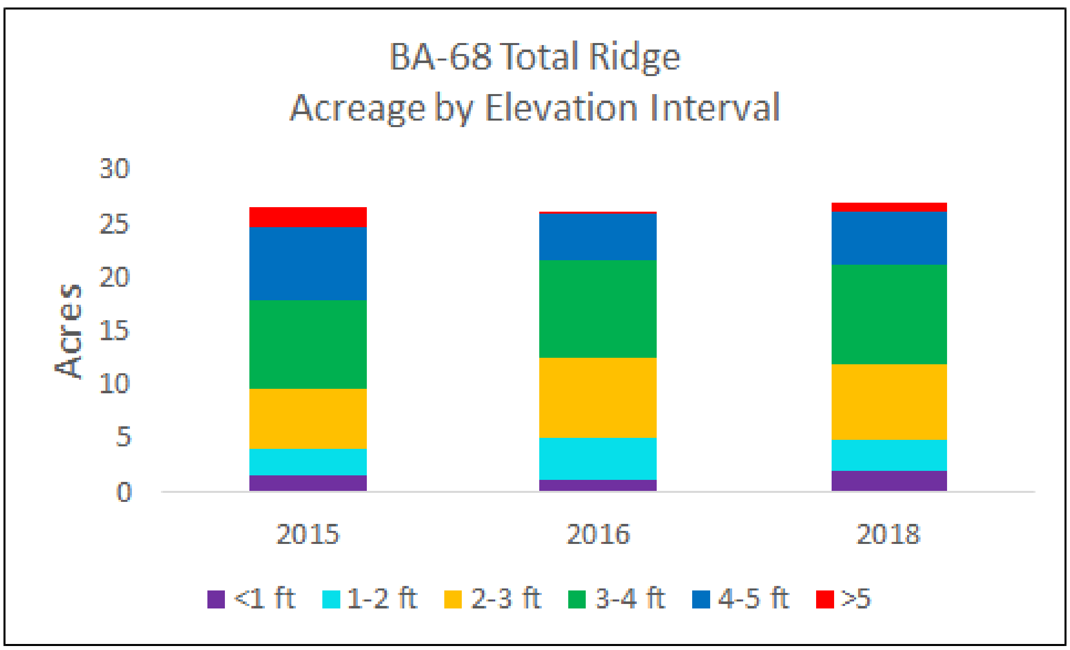

Figure 23. Acreages quantified within 1-foot elevation intervals for the combined BA-68 ridge areas from 2015 (as-built) to 2018.

Vegetation

Marsh Vegetation

Herbaceous percent cover in 2019 was high in all 14 marsh plots (>75%) just four years after construction (Figure 24). All plots were dominated by *Spartina alterniflora* (smooth cordgrass), with only one other species, *Phragmites australis* (common reed), present in one plot at 5% cover. Mean percent cover of vegetation within the plots was 91.7% ± 8.7 and was not significantly different by marsh creation cell. It is important to note that the sample size varied between marsh creation cells since the number of plots established was relative to marsh creation cell size (Figure 6). This resulted in the establishment of 5 plots in Cell A, 4 plots in Cell B, 3 plots in Cell C, and 2 plots in Cell D. It does not appear that the results are skewed by the uneven sample size given the universally high plot cover at the project site and the uniformity of data between sample plots.

The Floristic Quality Index (FQI) is a tool used to determine habitat quality based on plant species composition, and a modified FQI (scaled from 0 to 100) was developed for coastal Louisiana to assess vegetation condition at the CRMS sites across various spatial and temporal scales (Cretini et al. 2012). The mean FQI calculated for the BA-0068 marsh plots in 2019 was 92 ± 8.3 and was not significantly different by marsh creation cell. Since *S. alterniflora* has the highest possible coefficient of conservatism score of 10 (Cretini et al. 2012) and since it was the dominant species, high FQI scores resulted. The marsh vegetation data collected at BA-0068 were compared to vegetation data collected in 2019 at CRMS0179, a natural saline marsh site located approximately 13.5 miles west of the project site. Percent cover and FQI were not significantly different between the BA-0068 and CRMS0179 sites. Mean percent cover within the 14 plots at BA-0068 ranged from 75% to 100%, while at the ten CRMS0179 plots it ranged from 70% to 100%. The NMDS analysis was conducted to investigate plant community differences, and no significant differences were detected. The BA-0068 project had a FQI higher than the 90th percentile when compared to other saline marshes across the coast, all marshes in the Barataria Basin, and all marshes coast-wide (Figure 25). The CRMS0179 FQI was between the 75th and 90th percentile when compared to other saline marshes and higher than the 90th percentile when compared to Barataria Basin and coast-wide marshes.

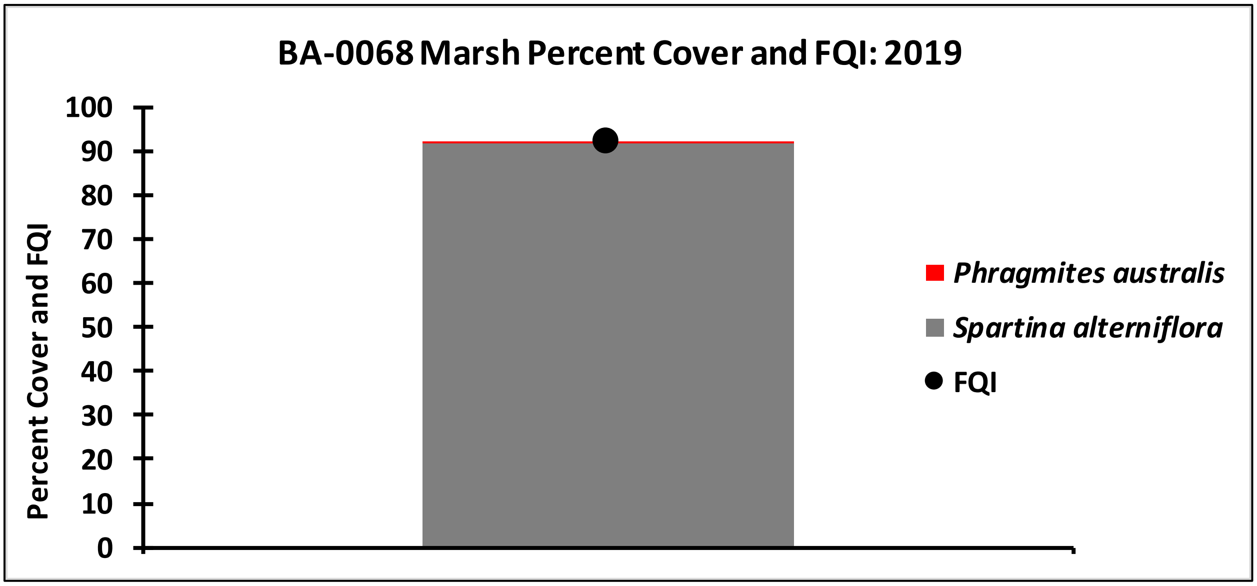

Figure 24. Mean percent cover by species and FQI for the BA-0068 marsh vegetation plots in 2019.

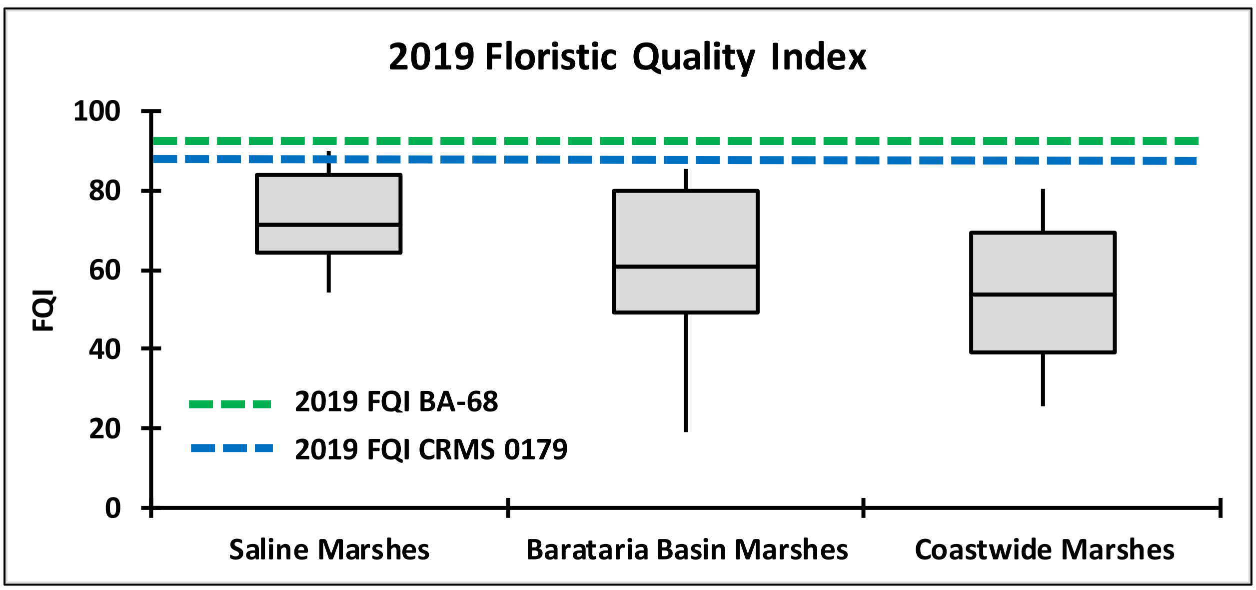

Figure 25. The 2019 Floristic Quality Index (FQI) for BA-0068 and CRMS0179 compared to the FQI for all saline marshes, all marshes in Barataria Basin, and all marshes coast-wide. The boxplots represent the 10th, 25th, mean, 75th, and 90th percentiles.

Ridge Vegetation
Herbaceous and shrub vegetation data were collected in 2019 and 2020 within fourteen 2-m x 2-m plots along the BA-0068 ridge (Figure 6). Percent cover (always ≤ 100%), percent herbaceous cover, total percent cover (addition of all species covers, can be > 100%) and FQI were not significantly different by year, ridge creation cell, or their interaction. Mean percent cover in 2019 was 68.9% ± 21.7 and increased to 73.9% ± 16.9 in 2020. Percent shrub cover was significantly different by year (p=0.035), but not by ridge creation cell or their interaction. Mean shrub cover increased from 2.5% ± 7 in 2019 to 15.1% ± 20 in 2020. The increase in shrub cover is attributable to the appearance of *Baccharis halimifolia* (eastern baccharis) with over 10% cover in 2020 after it was not present in 2019 (Figure 26). The large standard deviation for mean shrub cover in 2020 indicates that there was a large variation in shrub cover between plots as patchy shrub colonization occurred. In 2019, the highest shrub cover among the 14 plots was 25% and in 2020 it was 60%. Also, in 2019, two of the 14 plots had shrub cover, while in 2020, 12 of the 14 plots had shrub cover. The species with the highest percent cover in both years was *Distichlis spicata* (saltgrass), followed by *P. australis* and *Paspalum vaginatum* (seashore paspalum) (Figure 26). In general, the species with high percent cover were present in both years, while some species with low cover disappeared or appeared between 2019 and 2020. This would be expected in a newly built environment as species colonize and then are outcompeted as species more adapted to the environment move in.

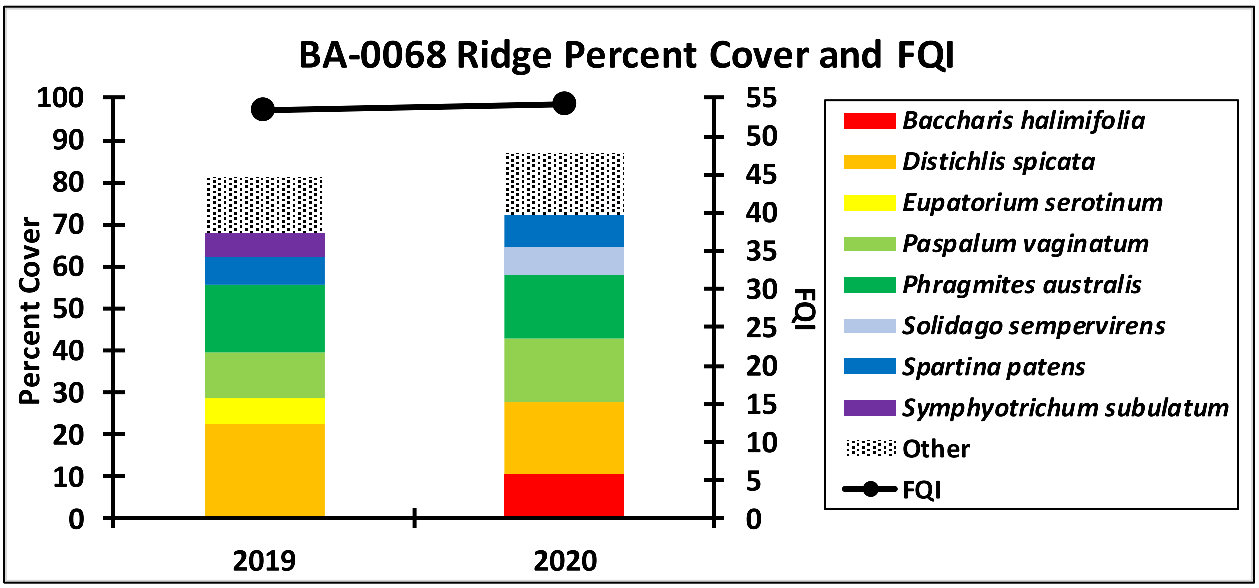

Figure 26. Percent cover and FQI of the herbaceous vegetation on the ridge in 2019 and 2020 at the BA-0068 project.

In 2020, additional ridge data were collected within eight 6-m x 6-m understory plots along the BA-0068 ridge (Figure 6). All woody trees and shrubs ≥50 cm in height were identified and diameter at breast height (DBH) was measured for all specimens ≥137 cm in height. Ridge understory vegetation was dominated by *B. halimifolia* (34 individuals), which naturally colonized the site, while all other woody species found in the understory were from the tree planting (described below). The planted species with the most live individuals within the combined plots were *Quercus virginiana* (live oak) and *Morus rubra* (red mulberry), both with 13 individuals. When number of stems are taken into account, *B. halimifolia* had 136 stems, indicating that both the number and biomass of this species was much higher than the planted trees. *B. halimifolia* is a beneficial species to quickly colonize the ridge, because its roots can help prevent erosion, it is resistant to salt spray, and it provides habitat and nesting area for birds (USDA, NRCS 2021). Plant height was not significantly different by species, plot, or their interaction. Mean height for all understory plants was 132.6 cm ± 34.1, with a maximum height of 204.2 cm (*M. rubra)* and a minimum height of 61 cm (two trees, *B. halimifolia* and *Ilex vomitoria* (yaupon)). The species with the tallest mean height was *M. rubra* (154.0 cm ± 31.4) and the species with the shortest mean height was *Callicarpa americana* (American beautyberry) (101.3 cm ± 29.5).

<u>*Planting Survival*</u>

Survivorship of 1,050 seedlings representing ~29% of the total ridge planting (Table 1) was evaluated along seven survivorship transects (Figure 6) approximately 3 months post-planting in October 2020 and 1-year post-planting in June 2021. It is important to note that between the two survivorship surveys, the project area was impacted by Hurricane Zeta, which made landfall in Louisiana on October 28, 2020 as a Category 3 hurricane. The hurricane crossed Barataria Basin, putting the project on the stronger, east side of the storm. Estimates of storm surge indicate that the project area most likely experienced storm surge heights between 7 and 10 feet (Blake et al. 2021), enough to over top the ridge. During the 2021 field survey, there was evidence of wrack deposition and some trees were buried or leaning over as a result of the storm. Some of the trees could not be found. An additional assessment was conducted in November 2021 to assess project performance after Hurricane Ida. Hurricane Ida made landfall in Louisiana on August 29, 2021 as a Category 4 hurricane. The hurricane crossed along the western edge of Barataria Basin, again putting the project on the strong side of the storm. Final data on actual storm surge heights were not available at the time of writing, but projections for the project area were storm surge heights greater than 9 ft., which would again over top the ridge.

At 3 months post-planting, overall survival of the trees planted on the ridge was 89.4% which decreased to 64% at 1-year after planting and further decreased to 61% after Hurricane Ida; however, 16% of the trees that were assessed in 2020 could not be located in 2021, and some of those could still be alive.

Survival on the ridge was significantly different by year (repeated measures analysis, $p<0.001$ for both). Two species had diminished survival, *Morella cerifera* (wax myrtle) at 52.4% in 2020, 37% in June 2021, and 30% after Hurricane Ida in November 2021, and *Diospyros virginiana* (common persimmon) at 53.3% in 2020 and 30% in June 2021, and experienced no further mortality after Hurricane Ida (Figure 27). These two species had the least number of individuals planted (especially common persimmon at only 65 individuals), and therefore were the least represented in the survival transects. These species seemed to experience rapid mortality in the first 3 months, then the rate leveled off somewhat for both species. The remaining species all had survival rates above 85% in 2020. The species with the highest survival rate was *Celtis laevigata* (sugarberry) at 97.6% in 2020, as well as the highest in June 2021 at 78% and in November 2021 at 72%. Survivorship of all species decreased between the first two surveys, and then decreased slightly from the second to the third survey (except common persimmon).

Survival was not significantly different by creation cell in 2020, but it was in June and November of 2021 (Figure 28). In 2020, Cell D, at 98%, had higher survival than the other three cells, where survival ranged from 86.9% to 89.3%. In November 2021, survival was significantly different by cell ($p<0.001$), year ($p<0.001$), and their interaction ($p=0.02$). In November 2021, Cell A had significantly lower survival than Cells C ($p<0.001$) and D ($p=.002$). Survival in November 2021 was 29% in Cell A, 56% in Cell B, 79% in Cell C, and 73% in Cell D (Figure 29). It should be noted that fewer plants were installed along the ridge in Cell A (Table 1) due to the presence of several dense stands of *Phragmites australis* (common reed) along that area of the ridge.

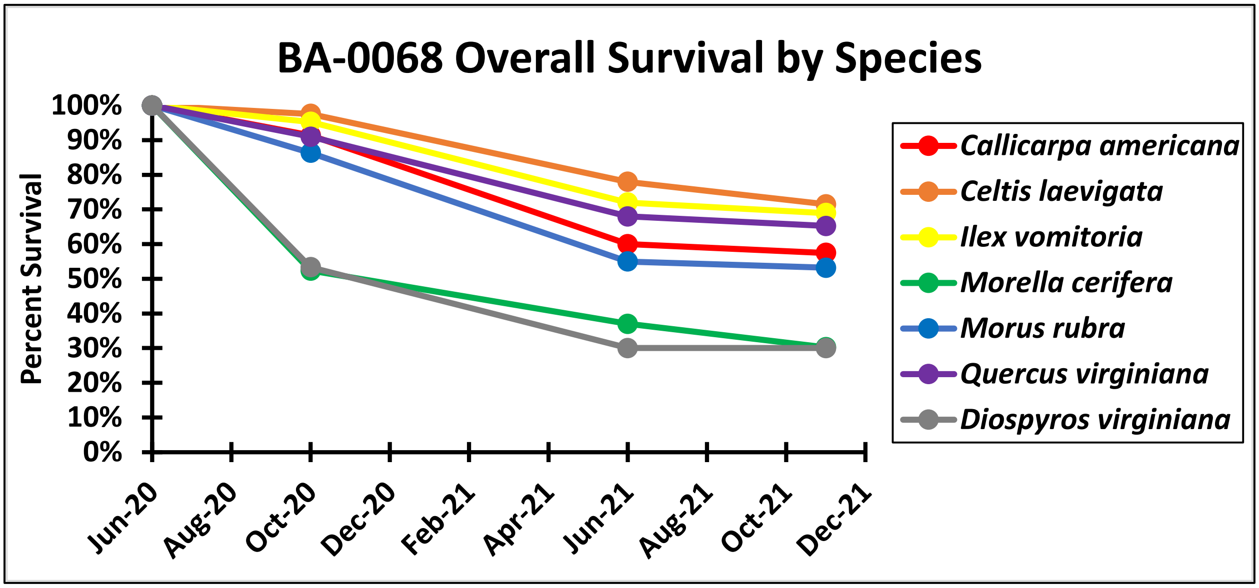

Figure 27. Survival of planted trees by species on the restored BA-0068 ridge over time.

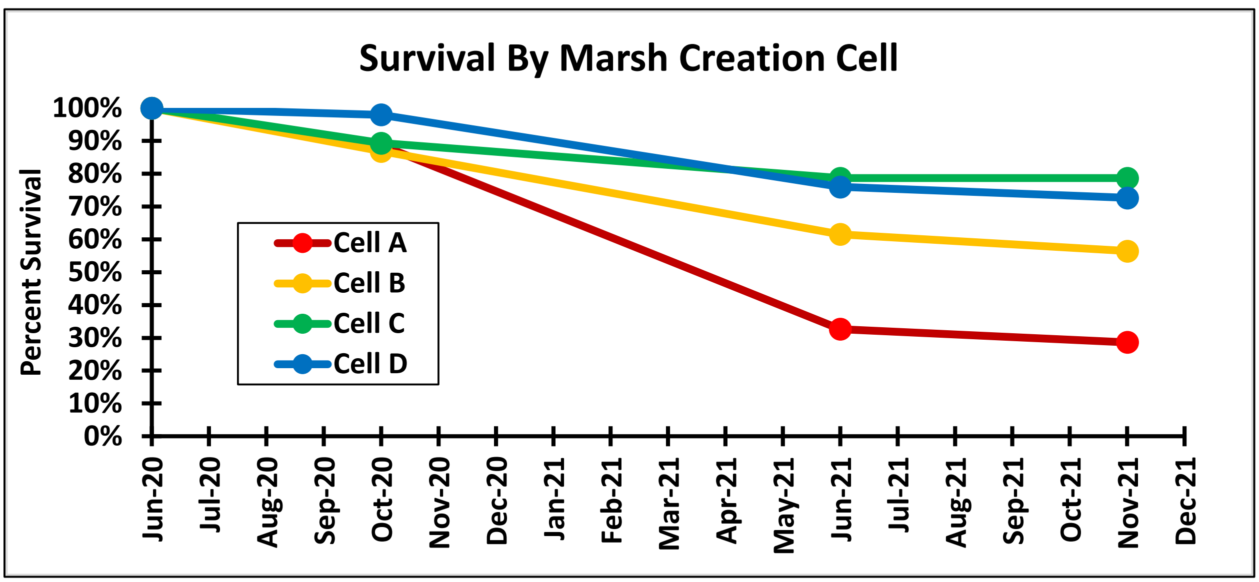

Figure 28. Survival of planted trees by cell on the restored BA-0068 ridge over time.

During data collection, trees that were alive but appeared stressed were noted (except in the November 2021 survey). In 2020, the percentage of stressed trees was significantly different by species ($p<0.001$), but not by creation cell. In 2021, the percentage of stressed trees was significantly different by species, year, and their interaction ($p<0.001$ for all), using repeated measures analysis, but not by creation cell. In 2020 the species with the most stressed trees was *C. laevigata* at 73.3%, followed by *M. rubra* at 71.8% (Figure 30). *C. americana* and *D. virginiana* also had more than 50% stressed trees at 61.4% and 50%, respectively. The species with the lowest amount of stressed trees was *M. cerifera* at 6.9% and *I. vomitoria* at 7.1%. Therefore, while *C. laevigata* and *M. rubra* had relatively high survival rates, many of the surviving trees appeared stressed. The trees were planted in June, which is late for woody plantings in south Louisiana due to the high potential for heat stress. By June of 2021, the percentage of stressed trees had decreased in all species and the percentage of healthy trees had increased in 5 of the 7 species. It appears that many of the trees that appeared stressed in 2020 had recovered in 2021. It is difficult to discern patterns of recovery and mortality due to some trees not being found during the second survey. It is most likely that a large percentage of the missing trees will not be found in subsequent surveys and their status will change from missing to dead. The missing trees could be buried by wrack or blown over/away by the hurricane, or just difficult to locate in heavy brush.

Prior to the tree planting in 2020, a test planting of 280 trees (10 trees of each species, in each cell) was conducted in 2019 to assess whether the ridge was ready for planting. Survival and vigor was assessed at 50 days and six months after planting. The results of the 50 day survey were not similar to the results of the three month survey described above as all species had high survival in the test planting. While there was no difference in survival by cell in the test plantings at 50 days, Cell D did have the highest percentage of healthy trees (not stressed), which is similar to the results described above. In the 6-month post-test planting survey, *M. cerifera* did have the lowest survival rate at 35%, and *D. virginiana* had the next lowest survival at 51.3%, which is a similar pattern to the results described above. Other species in the test-planting had lower survival rates 6-months after planting than the results above, 3-months after planting. Cell D also had the highest survival rate after 6 months. In general, the patterns of the results 3-months after the planting are similar to the results 6-months after the test planting, but the actual survival numbers are lower 6-months after the planting. A similar project also constructed in 2015, the Bayou Dupont Marsh and Ridge Creation (BA-0048), has the same species planted on the constructed ridge. Tree survival at the BA-0048 project was 92% after one year (September 2020), but has not been assessed since Hurricanes Zeta and Ida. Over time, the monitoring of these two projects and the Fourchon Ridge project mentioned above, can guide plantings at future projects in regard to ideal conditions and species with greatest chance of success.

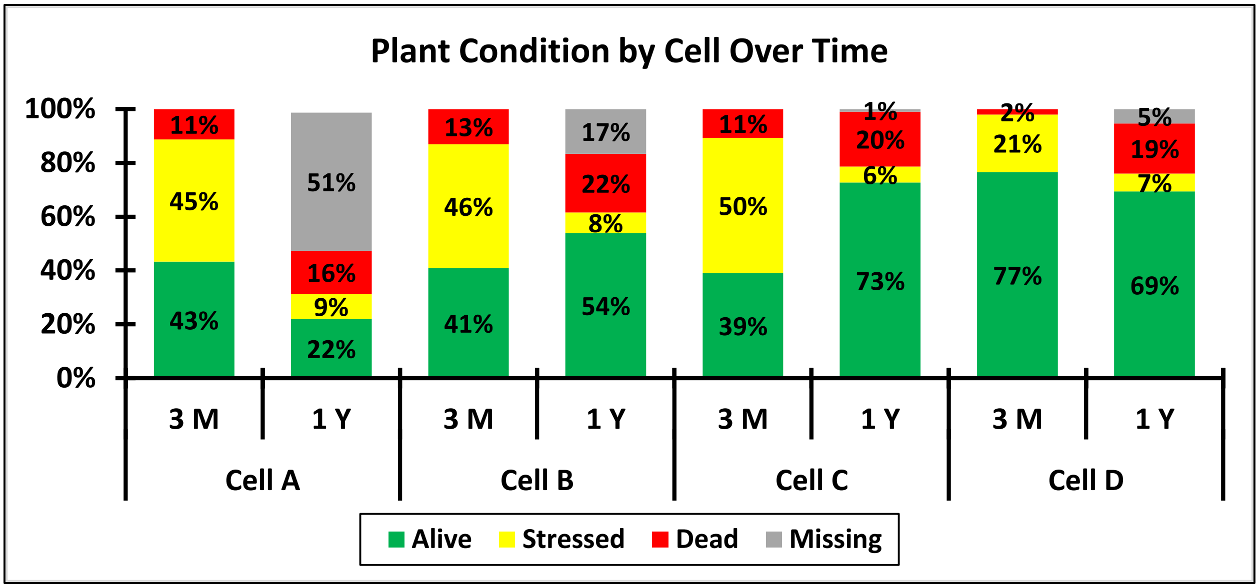

Figure 29. Planted tree condition by cell at the BA-0068 ridge restoration site [3M = 3 months after planting (October 2020) and 1Y = 1 year after planting (June 2021)].

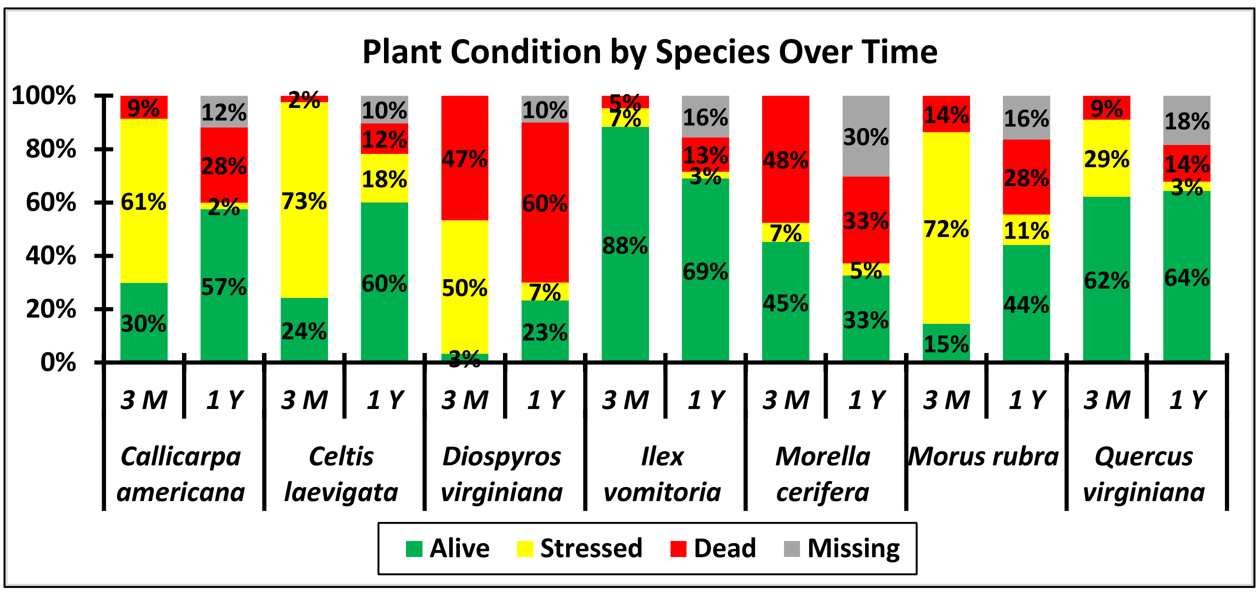

Figure 30. Plant condition by species over time at the BA-0068 ridge restoration site [3M = 3 months after planting (October 2020) and 1Y = 1 year after planting (June 2021)].

Sediment Properties

September 2018 Soil Core Analysis
As described in Section IV.b., individual soil cores were collected at 8 locations on the ridge in September 2018 (Year 3) following CRMS methodology (Folse et al. 2020), with two cores being collected along each of the four fill cells (Figure 6). Soil properties analyzed include organic matter (%), pH, specific conductance (µS/cm), soil salinity (ppt), bulk density (g/cm^3), moisture content (%), and wet/dry volume (cm^3). For each soil core, analyses were conducted in 4 cm depth increments from the surface to a total depth of 24 cm (6 total increments).

The soil parameters of percent soil moisture, bulk density, percent organic matter and wet/dry ratio were not significantly different by depth or cell. Mean soil moisture was 24% ± 7%, mean bulk density was 1.27 ± 0.26 g/cm^3, mean percent organic matter was 4.5% ± 1.7%, and mean wet/dry ratio was 1.78 ± 0.53. The lower moisture content would be expected of a ridge environment where soils are not flooded and the main source of moisture is rainfall. The ridge was built with dredge soil from Bayou Grand Liard, which predominantly consisted of clay, silt and sand (Langlois 2011). The high bulk density and low organic matter is what would be expected from newly placed dredge material with high mineral sediment content.

The pH was significantly different by cell ($p<0.001$) with Cell D having significantly higher pH (mean: 8.3 ± 0.06) than cells B (mean: 7.7 ± 0.24) and A (mean: 7.4 ± 0.5) (Figure 31); therefore, Cell D was almost 10 times more alkaline than Cell A. The pH was not significantly different by depth. Mean pH across all cells was 7.8 ± 0.4. The soil salinity was significantly different by depth ($p=0.12$) with the deepest depths at 20 to 24 cm (mean: 1.9 ± 0.7 ppt) and 16 to 20 (mean: 2.1 ± 0.9 ppt) having significantly lower salinity than the shallowest depth at 0 to 4 cm (mean: 5.05 ± 3.7 ppt). In general, the soil salinity decreased with depth (Figure 32). Soil at the surface is exposed to drying sunlight. If the dredge spoil that was placed had elevated soil salinity, then the salt can become concentrated under drying conditions that are not experienced by deeper soils. It would be expected that the high soil salinity would eventually be flushed out by freshwater rains; however, this could take some time, especially if the soils are predominantly clays, which are harder to flush. Soil salinity was not significantly different by cell. Mean soil salinity across all samples was 2.9 ± 1.96 ppt.

NMFS Soil Samples: December 2015 through May 2019
As described in Section IV.b., sediment samples were collected from each of the four ridge sections approximately every six months after construction (Dec 2015, Jun 2016, Dec 2016, Jun 2017, Jan 2018, July 2018, May 2019), and analyzed for calcium (ppm), chloride (ppm), magnesium (ppm), salts (ppm), sodium (ppm), sulfur (ppm), iron (ppm), potassium (ppm), manganese (ppm), phosphorus (ppm) and electrical conductivity (EC) (dS/m), pH, and Sodium Adsorption Ratio (SAR).

The soil constituents of sulfur (S), iron (Fe), manganese (Mn) and phosphorus (P) were not significantly different by time or by cell. Soil S increased from December 2015 through December 2016, then decreased through July of 2018 and remained level through May 2019. Soil Fe remained

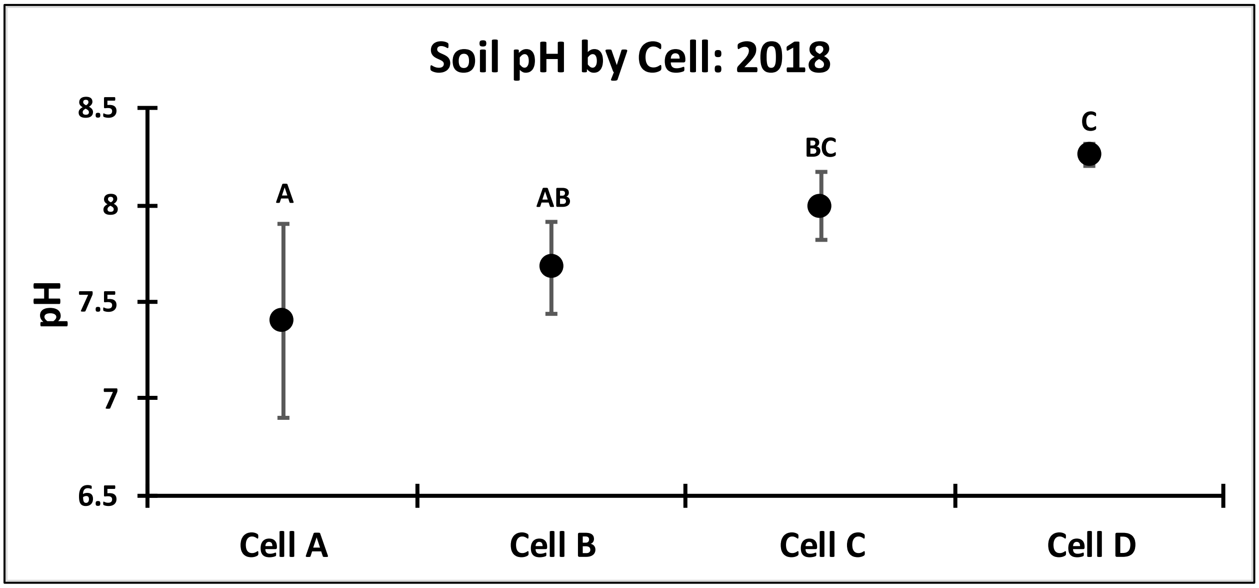

Figure 31. Soil pH by cell from the September 2018 sampling event. Points with the same letters are not significantly different from each other.

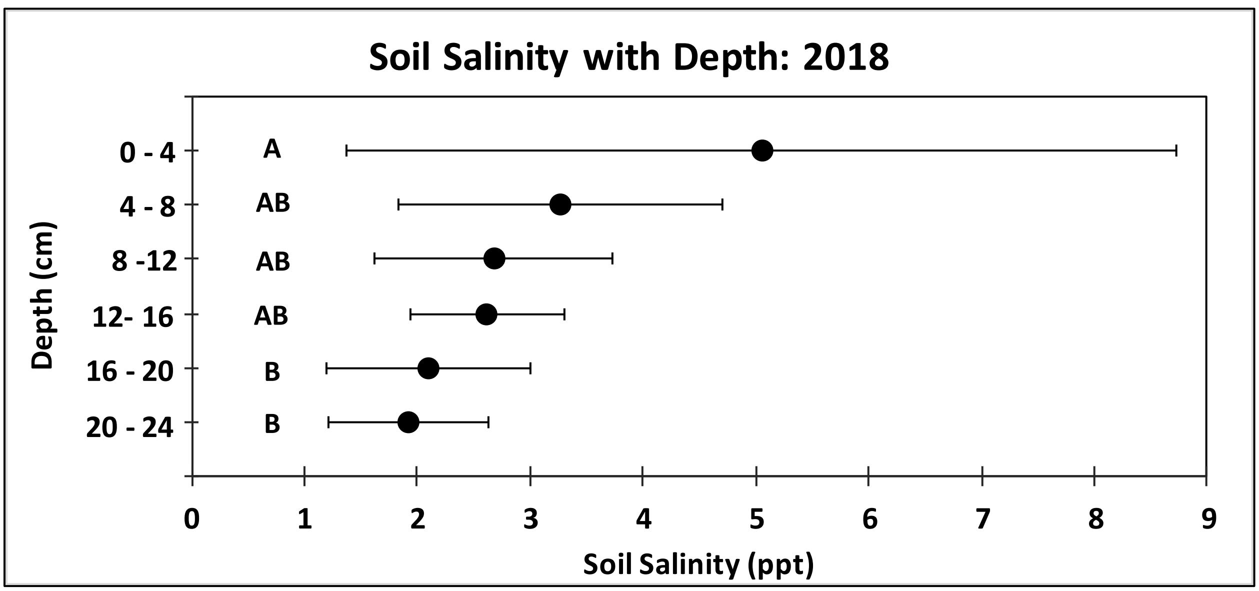

Figure 32. Soil salinity with depth across all cells from the September 2018 sampling event. Points with the same letters are not significantly different from each other.

relatively low throughout most of the project (mean 2015-2018: 0.09 ± 0.14 ppm) except for a high value in the most recent sampling event in May 2019 (mean: 0.92 ± 1.3 ppm). There was a high value from Cell A in May 2019 (2.8 ppm) that increased the mean from this sampling event, but even when this value was removed, the mean was still elevated when compared to previous sampling events (0.28 ± 0.32 ppm). Soil Mn fluctuated between low and elevated for the first four sampling events, then remained low the remainder of the study. The elevated values in June 2016 and June 2017 were driven by high values from Cell A (4.85 and 5.67 ppm, respectively, rest of data mean: 0.2 ppm). Soil P remained relatively low throughout most of the project (mean 2015-2018: 0.2 ± 0.09 ppm) except for a high value in the most recent sampling event in May 2019 (mean: 1.15 ± 1.18 ppm). There was an high value from Cell A in the May 2019 (2.9 ppm) that increased the mean from this sampling event, but even when this value was removed, the mean was still elevated when compared to previous sampling events (0.56 ± 0.12 ppm).

The pH was significantly different by cell (p=0.005) with Cell A having significantly lower pH (6.26 ± 1.1) than all other cells (mean of Cells B-D: 7.48 ± 0.42) (Figure 33); therefore, Cell A was over 10 times more acidic than the other cells. These results are similar to the results from the 2018 sampling described above where Cell A had significantly lower pH than Cells C and D. Cell A had four of the lowest values measured in the study, with the lowest value of 4.53 measured in the May 2019 sampling event. Soil pH was not significantly different over time. The May 2019 sampling event had the lowest pH found in each cell. Mean pH at the beginning of the study in December 2015, across all cells, was 7.66 ± 0.35 and was 6.22 ± 1.15 by May 2019 which results in soils changing from alkaline to circumneutral (Tiner 1999, Mitsch and Gosselink 2000).

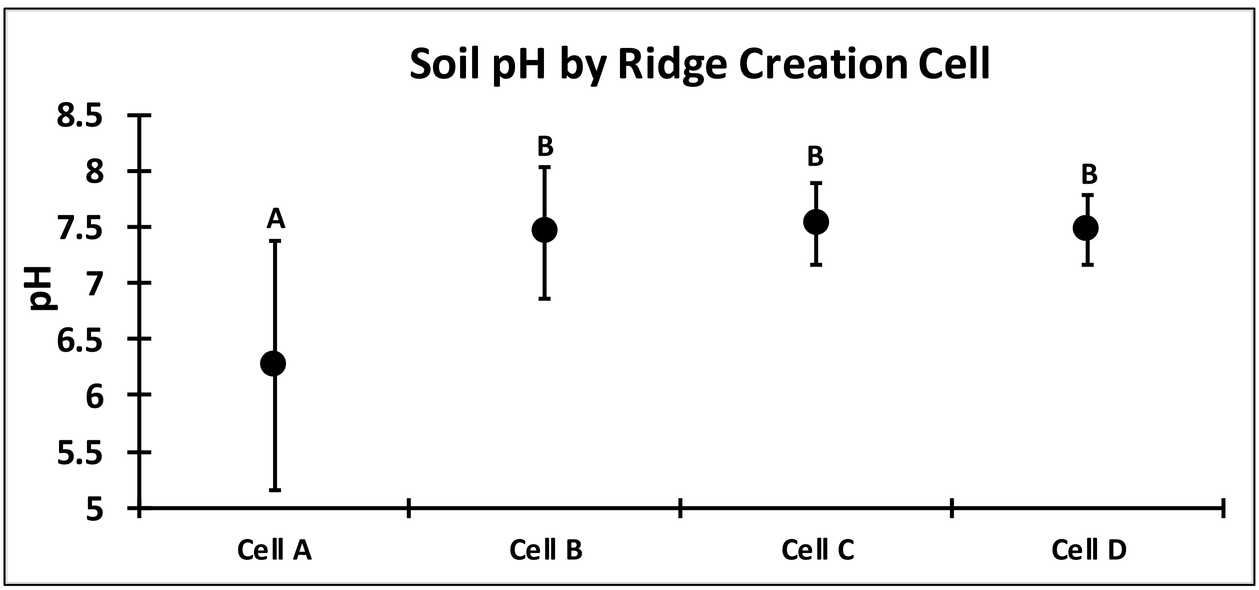

Figure 33. Soil pH by cell across all sampling dates. Points with the same letters are not significantly different.

The remaining soil constituents were all significantly different over time and will be discussed individually below. Soluble salts and electronic conductivity (EC) were highly correlated (R^2 = 1.0, $F_{(1,26)} = 4.65 \times 10^{32}$, p<0.001), indicating that soluble salt concentration was the main driver of soil electronic conductivity. Mean soluble salt concentration was significantly different over time (p=0.003). Soluble salts increased from December 2015 through December 2016, decreased through January 2018, increased in July 2018 and decreased to the lowest value in the study in the May 2019 sampling (Figure 34). Mean soluble salt concentration was higher than the threshold for 50% tree survival found at Fourchon Ridge (Benoit 2016) throughout the entire study period. However, the most recent value from May 2019 (mean: 8.38 ± 5.0 ppt) is approaching the threshold of 8.022 ppt. Only Cell C failed to meet this threshold in the most recent sampling date. The mean EC was also significantly different over time (p=0.003) and followed the same pattern as soluble salts (Figure 35). The EC was higher than the threshold for 50% tree survival found at Fourchon Ridge (Benoit 2016) for the entire study period expect for the most recent sampling event in May 2019 where the mean EC (13.1 ± 7.8 dS/m) was just below the threshold of 13.3 dS/m. Again, Cell C failed to mean the threshold with an EC of 24.46 dS/m.

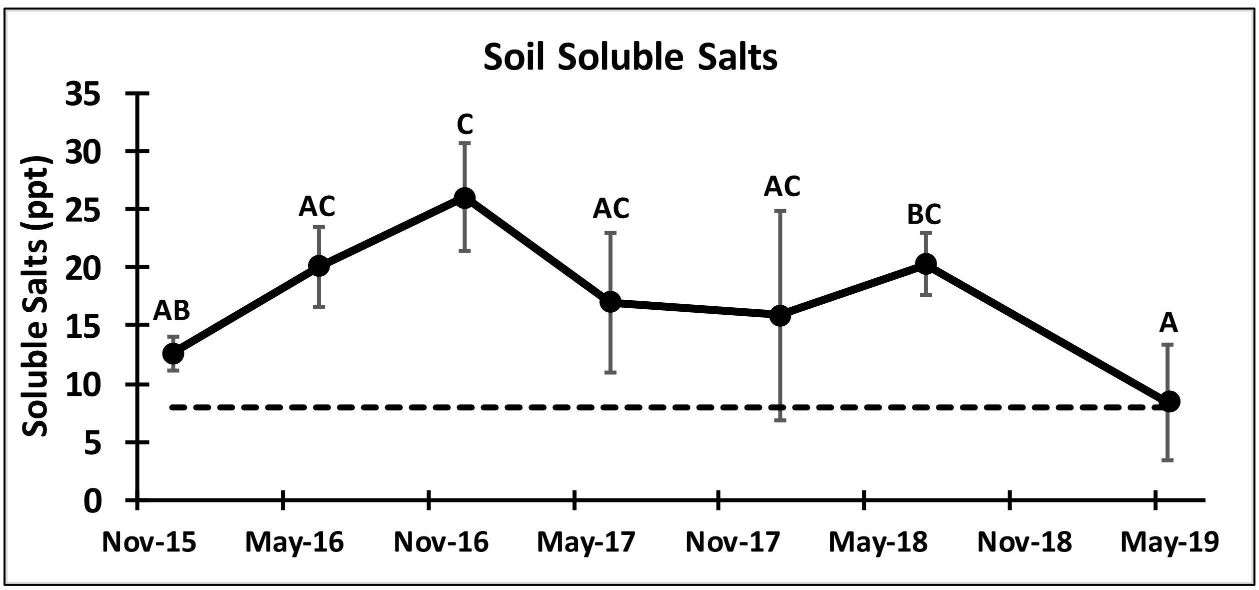

Figure 34. Mean soil soluble salts over time across creation cells at Grand Liard Ridge Restoration. Dashed line is the threshold for 50% tree survival found in Benoit 2016. Points with the same letters are not significantly different.

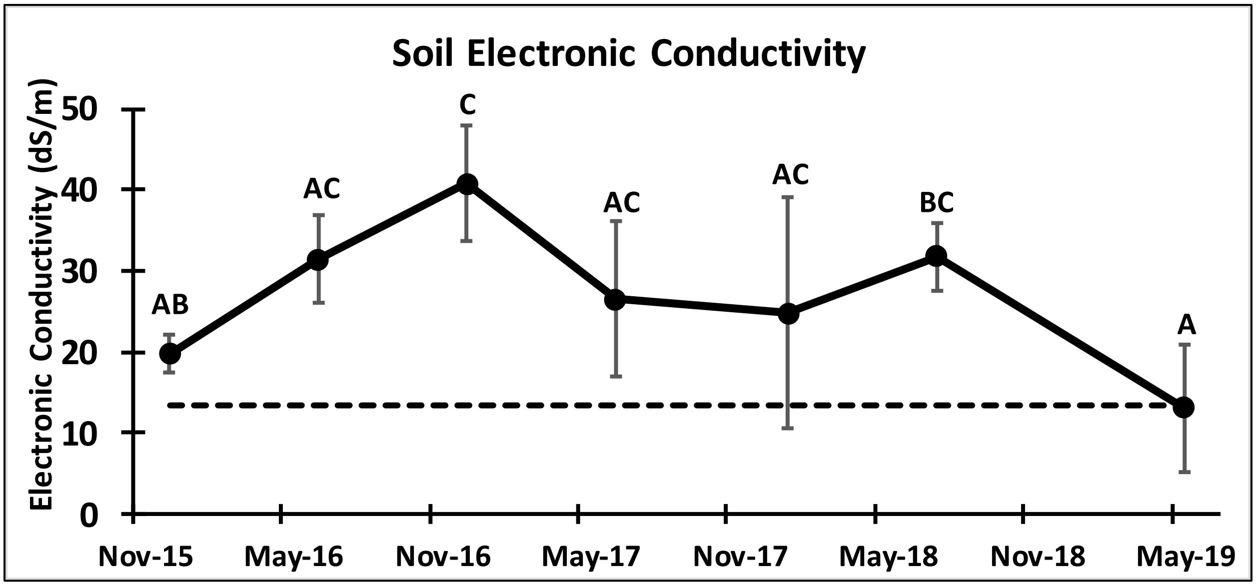

Figure 35. Mean soil electronic conductivity over time across creation cells at Grand Liard Ridge Restoration. Dashed line is the threshold for 50% tree survival found in Benoit 2016. Points with the same letters are not significantly different.

Soil sodium (Na) concentration and soil sodium adsorption ratio (SAR) were highly correlated ($R^2 = 0.96$, $F_{(1,26)} = 736.9$, $p<0.001$). Both Na and SAR had high values in December 2015 and July 2018 and low values for all other sampling dates. The high values were above the 50% tree survival threshold (2,634 ppm for Na and 22 for SAR) and the low values were all below this threshold (Figures 36 and 37).

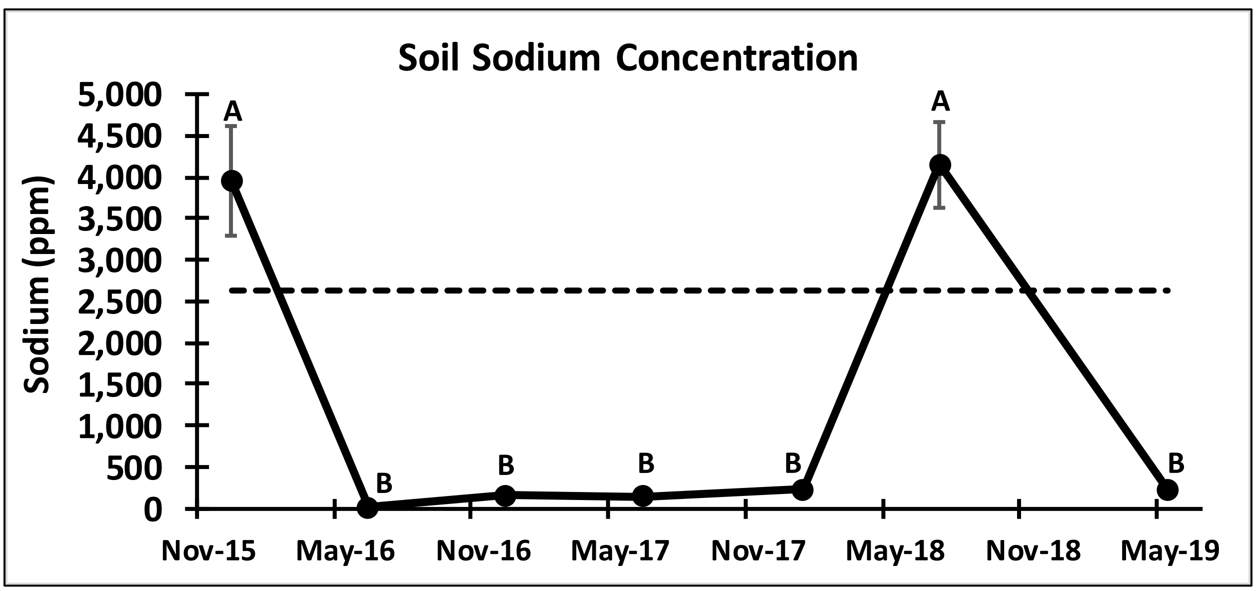

Figure 36. Mean soil sodium concentration over time across creation cells at Grand Liard Ridge Restoration. Dashed line is the threshold for 50% tree survival found in Benoit 2016. Points with the same letters are not significantly different.

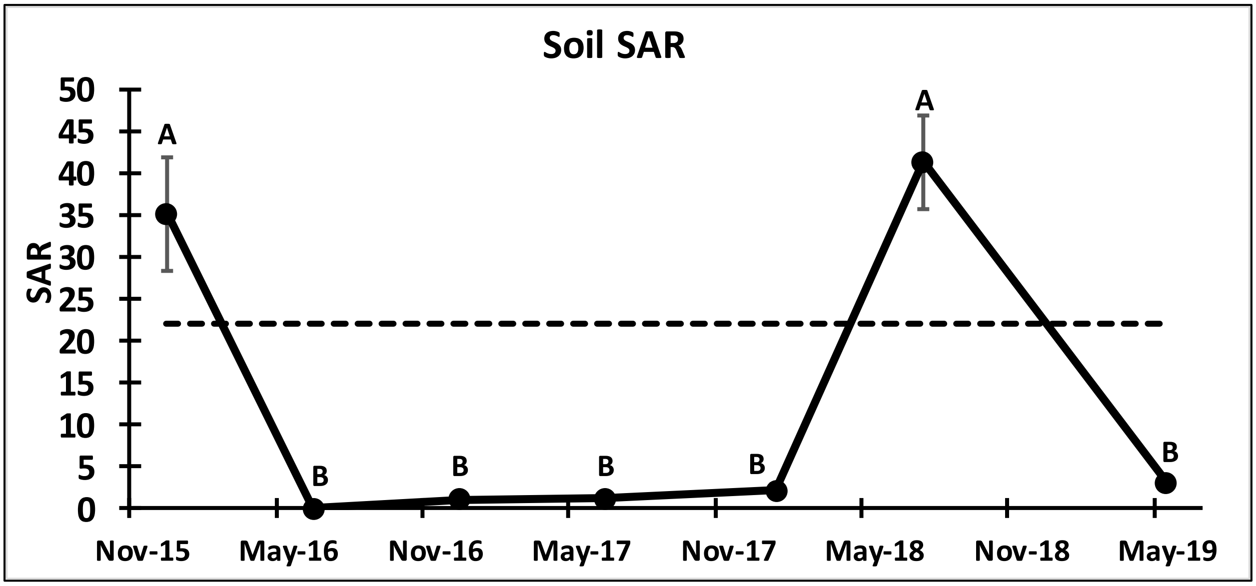

Figure 37. Mean soil sodium adsorption ratio (SAR) over time across creation cells at Grand Liard Ridge Restoration. Dashed line is the threshold for 50% tree survival found in Benoit 2016. Points with the same letters are not significantly different.

Mean soil chloride (Cl) concentration was significantly different over time ($p<0.001$) with elevated values in June 2016 and July 2018 (Figure 38). The lowest Cl concentration was found in the most recent sampling event, May 2019, at 1,681 ± 553 ppm. Soil Cl concentration fluctuation was not correlated with any other soil constituent that was sampled in this study and was not significantly different by cell.

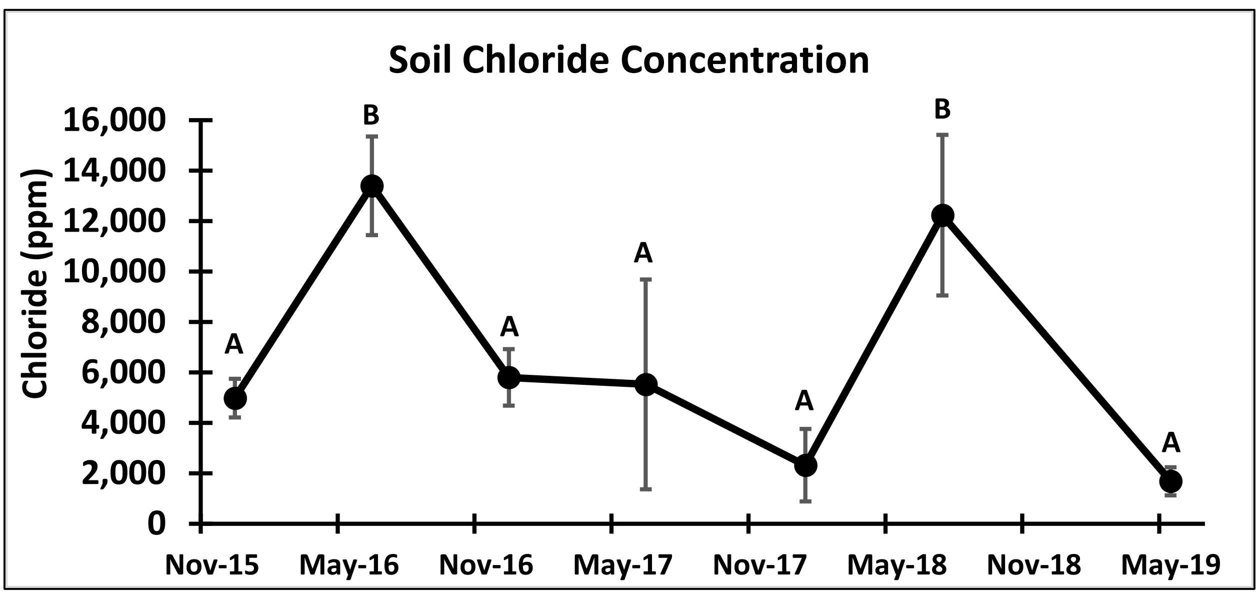

Figure 38. Mean soil chloride concentration over time across creation cells at Grand Liard Ridge Restoration. Points with the same letters are not significantly different.

Mean soil calcium (Ca) and magnesium (Mg) concentrations followed similar patterns increasing from December 2015 to December 2016, then decreasing for the remainder of the study with the lowest values in the most recent sampling event (May 2019). Mean soil Ca concentration was significantly different over time (p=0.0007) and had a concentration of 151 ± 33 ppm at the end of the study (Figure 39). Soil Mg concentration was also significantly different over time (p=0.033) and had concentration of 150 ± 58 ppm at the end of the study (Figure 40). Soil Ca and Mg were not significantly different by marsh creation cell.

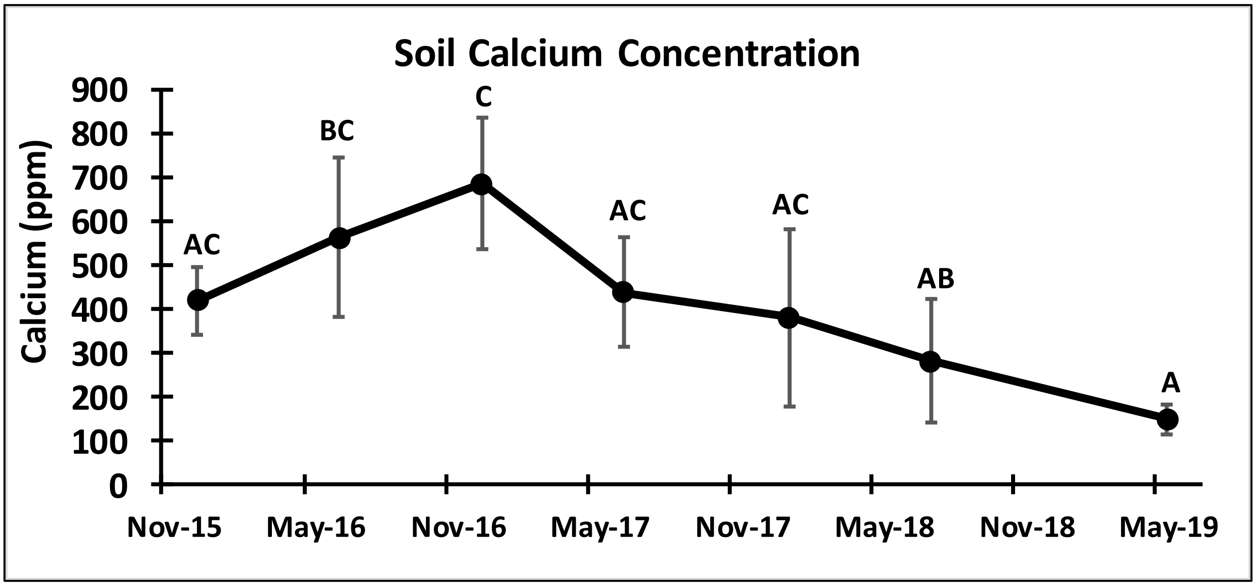

Figure 39. Mean soil calcium concentration over time across creation cells at Grand Liard Ridge Restoration. Points with the same letters are not significantly different.

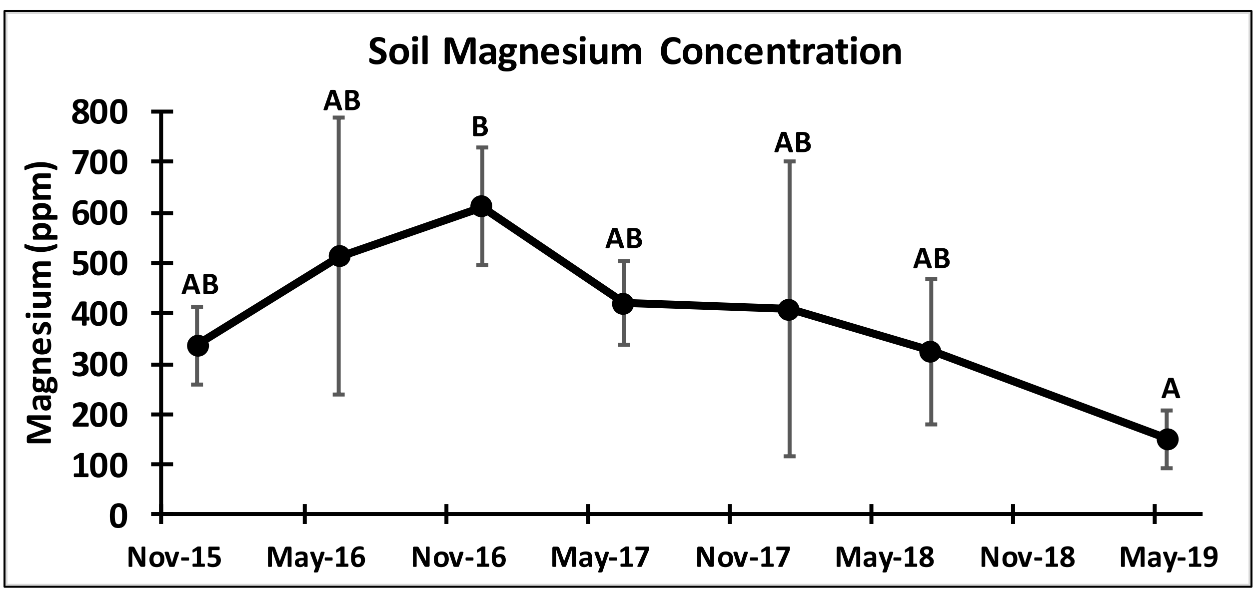

Figure 40. Mean soil magnesium concentration over time across creation cells at Grand Liard Ridge Restoration. Points with the same letters are not significantly different.

Overall, the soils at the Grand Liard Ridge Restoration project have become more conducive to tree growth over time, with most soil constituents for which there is a 50% survival threshold developed (Benoit 2016), reaching or surpassing that threshold by May 2019. Other constituents, for which there is not an established threshold, have all decreased over time as well. Some fluctuations may still be occurring that could impact planted trees as indicated by soil sodium concentrations, which were low and below the threshold for four successive sampling events, spiked above the threshold in July 2018, and then returned to adequate levels in May 2019. However, the sudden increase in shrub species noted between the 2019 and 2020 growing seasons (see previous *Ridge Vegetation* section) is an additional indication that soil chemistry was indeed becoming more amenable to the growth of woody vegetation by this time. By 2020, there were limitations to waiting for soil conditions to improve further before planting the ridge since the seedlings were at risk of becoming root-bound by that point and there was concern that *Baccharis* might quickly 'take over' the ridge making plant installation difficult (as occurred on the BA-0048 Bayou Dupont ridge project). However, based on satisfactory survival of the plantings at 3-months and 1-year following the June 2020 planting event, it appears that the soil condition was generally suitable for planting. It is possible that an initial planting of herbaceous vegetation on the ridge may have expedited soil chemistry development through earlier root penetration of the clay soils allowing for enhanced rainwater flushing. While there were cost-savings in not conducting this herbaceous planting, there were additional costs incurred to hold the woody plants until soil conditions improved.

V. Conclusions

a. Project Effectiveness

The Grand Liard Marsh and Ridge Restoration project has accomplished the overall project goal of restoring the eastern ridge of Bayou Grand Liard and re-establishing marsh habitat in previously open water areas to the east of the ridge. The specific objectives of the project were to: 1) create and nourish approximately 400 acres of saline marshes and associated edge habitat for aquatic species through pipeline sediment delivery; and 2) restore the Grand Liard ridge to reduce wave and tidal setup by constructing approximately 16,600 linear ft (over 20 acres) of maritime ridge habitat. Based on the 2016 land/water analysis, the 386 acres of land within the marsh fill areas (357 acres marsh/29 acres containment) were slightly below the 400 acre goal; however, this was only one year post-construction and it is possible that some areas of the marsh platform were still vegetating at this time.

The design goal of achieving a mean elevation within intertidal range by Year 3 post-construction was achieved in all marsh creation cells except for Area C, which was just approaching intertidal range. Mean marsh elevation by Year 3 was the lowest in Area B, which was the only area with a mean elevation below the predicted settlement curve and has already settled to the predicted Year +10 elevation. With the exception of Area B, mean elevation within the other fill areas are expected to remain within intertidal range for the duration of the 20-year life. The marsh platform within all four fill areas vegetated naturally with *Spartina alterniflora* soon after construction, and therefore a marsh planting was unnecessary. By 2019, the mean percent cover of vegetation within the combined marsh areas was 92%, and there was not a significant difference in percent cover between the marsh cells. Percent cover and FQI in 2019 were also not significantly different between the BA-0068 sites and a nearby natural saline marsh site (CRMS0179).

The ridge creation objective to create 16,600 linear ft (20+ acres) of ridge habitat was achieved with a total of 16,769 linear ft (28 acres) of ridge created. Re-dressing and maintenance of the ridge to design specs during the marsh construction sequence resulted in a higher than predicted mean crown elevation by Year +3 post-construction (~4 ft NAVD, G12B). This likely increased resilience of the ridge during two storm events, Hurricanes Zeta (2020) and Ida (2021), which overtopped the ridge during the post-construction period. The ridge remained intact during these events although some areas of erosion and scour were observed. Based on the pre-storm Year +3 survey, the ridge is expected to remain above marsh elevation beyond the duration of the 20-year project life; however, the effects of the overtopping events on ridge elevation will be captured during the next survey in Year +10 (2025).

Ridge soils were not amenable for planting of woody seedlings until Year +5 post-construction due to the initially high salt content in the borrow material sourced from Grand Liard. Colonization of natural woody species (primarily *Baccharis*) increased significantly along the ridge between 2019 and 2020 providing further evidence that soil chemistry had become conducive to support woody vegetation by 2020. By contrast to the BA-0068 project, natural colonization of woody species occurred soon after construction of the Bayou Dupont ridge (BA-0048), which was created from borrow material sourced from the Mississippi River. Survival of the plantings along the Grand Liard ridge was satisfactory considering the impacts of the two major storm events. Three months following installation of 3,650 woody saplings on the BA-0068 ridge, percent survival was high at 89%, then decreased to 64% following Hurricane Zeta at 1 year post-planting. Survival declined further to 61% following Hurricane Ida. Comparatively, the one year survival rate of woody seedlings planted on the Bayou Dupont ridge was 92% in September 2020 (pre-Hurricanes Zeta and Ida).

b. Recommended Improvements

An effort should be made in the near future to remove the tree protectors from the planted trees. The surviving trees are large enough that some are becoming hindered by the protectors and are now at lower risk of predation due to their size. Also, some protectors are coming loose and littering the project area. Although the cost of removing the protectors was not included in the original O&M budget, there should be sufficient O&M funds to complete this task.

c. Lessons Learned

- The Grand Liard and Bayou Dupont ridge projects may help to inform future ridge projects involving woody vegetation plantings. In the case of Grand Liard, the use of higher salinity in-situ material to construct the ridge resulted in a long holdover time for the saplings while soil chemistry reached acceptable levels. This increased costs and put the plants at risk of becoming root-bound. If the planting had been delayed any further, repotting the plants into larger containers would have been necessary. A planting of herbaceous grasses on the ridge soon after construction may have increased the permeability of the soil and helped the soil chemistry to improve more quickly. In the case of the Bayou Dupont ridge, which was constructed with material sourced from the Mississippi River, the ridge vegetated so quickly with native shrubs that some areas could not be planted. Ideal planting timing is highly dependent on borrow material used and development of soil chemistry following construction. It is recommended to have further discussions on various topics related to woody ridge plantings, including borrow source material, soil chemistry testing, the use of herbaceous plantings to improve soil chemistry, timing of grow-out, saplings versus seedlings, and spacing of plant installation.

- It would be preferable to begin work on the woody planting contract a year before needed, so there is no delay in installation beyond the optimum timeframe. It is also recommended that future O&M budgets include a tree protector removal cost. There has also been discussion on other projects about the need for tree protectors in certain environments, or if they can be omitted from the installation.

- It is important for advancements in construction capabilities to be incorporated into project design as soon as they become available. The Grand Liard project was designed based on outdated production rates for hydraulic dredges, which resulted in modifications to the construction sequence. The efficiency of the dredge used for construction cut the expected dredge time by about one-third. Because two lifts were required for the marsh construction, additional time was needed for the first lift to settle before the second lift was placed; therefore, it was required to suspend work for 60-days to achieve the design. Due to a good working relationship between CPRA and the contractor, an agreement was made for the contractor to find other work for the dredge during this period of delay to reduce additional costs incurred.

- The construction sequence, which required the elevation of the ridge to be maintained with in-situ material as the marsh was being constructed, resulted in the post-construction ridge elevation performing better than designed. These maintenance lifts essentially replaced losses due to primary settlement as it occurred over several months. Settlement predictions for future ridge projects using a similar construction sequence should be adjusted to more accurately predict ridge elevations throughout the project life.

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Appendix A
(Three Year O&M Budget Projection)

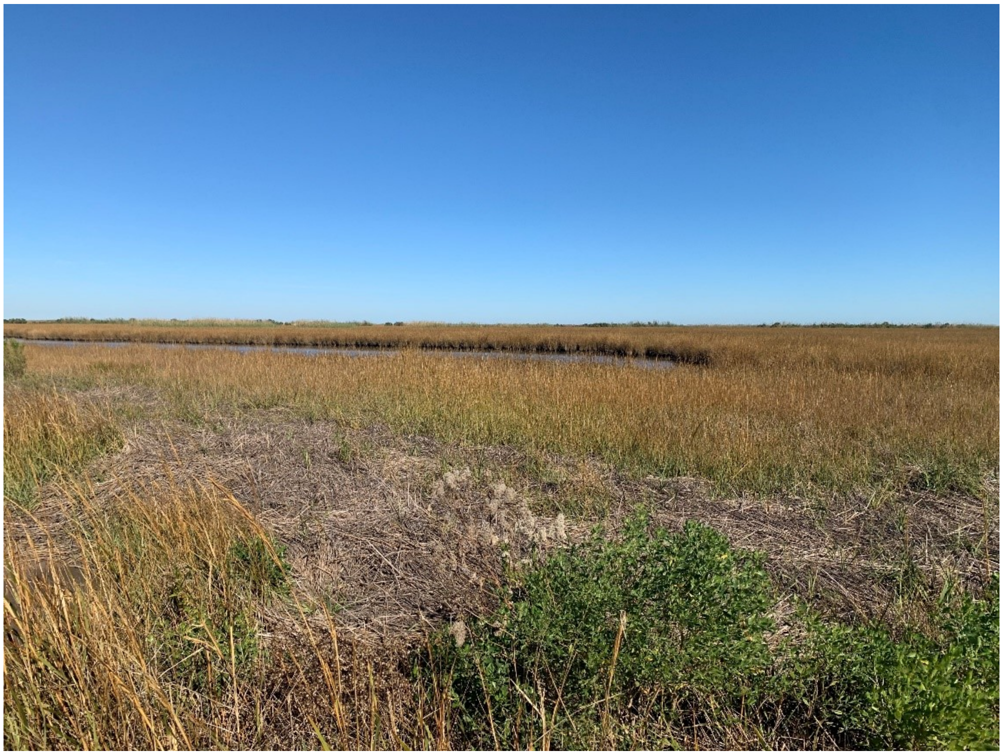
Grand Liard Marsh and Ridge Restoration (BA-68)																						
Federal Sponsor: NMFS																						
Construction Completed : 2015																						
PPL 18																						
Current Approved O&M Budget	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Project Life	Currently
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Budget	Funded
State O&M	$35,189	$6,425	$276,756	$6,659	$0	$11,130	$0	$11,534	$0	$41,834	$12,168	$0	$0	$12,837	$0	$0	$13,543	$0	$0	$28,287	$456,362	$325,028
Corps Admin	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$2,245	$25,520	$6,125
Federal S&A	$9,074	$0	$16,192	$0	$0	$0	$0	$0	$0	$10,028	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$35,294	$25,266
Total																					$517,176	$356,419
																					Remaining	Current
Projected O&M Expenditures																					Project Life	Budget
Maintenance Inspection	$6,312	$6,425	$6,541	$6,659		$11,130		$11,534			$12,168			$12,837			$13,543			$28,287	$78,370	$11,534
Construction:																					$0	$0
egetative Plantings/Tallow Control	$14,396		$87,546							$17,208											$17,208	$17,208
Dike Gapping			$43,750																		$0	$0
Subtotal with 25% Contingency	$17,995		$164,120							$21,509											$21,509	$21,509
State E&D	$1,808		$13,453							$2,122											$2,122	$2,122
Construction Inspection	$0		$32,700							$8,175											$8,175	$8,175
State S&A	$9,074		$16,192							$10,028											$10,028	$10,028
Federal S&A	$9,074		$16,192							$10,028											$10,028	$10,028
Total	$44,263	$6,425	$292,948	$6,659	$0	$11,130	$0	$11,534	$0	$41,834	$12,168	$0	$0	$12,837	$0	$0	$13,543	$0	$0	$28,287	$130,232	$63,397

O&M Expenditures from COE Report	$73,906	Current O&M Budget less COE Admin	$350,294	Current Project Life Budget less COE Admin	$491,656
State O&M Expenditures not submitted for in-kind credit	$0	Estimated O&M Expenditures to-date	$73,906	Total Projected Project Life Budget	$204,138
Federal Sponsor MIPRs (if applicable)	$0	**Remaining Available O&M Budget**	**$276,388**	**Project Life Budget Surplus (Shortfall)**	**$287,518**
Total Estimated O&M Expenditures (as of March 2020)	$73,906	Projected 3-Year Budget Expenditures	$78,370		
		3-Year Budget Surplus (Shortfall Request)	$198,018		

Appendix B
(Inspection Photographs)

Marsh in Cell A from the Ridge (11/30/2021)

Tree planted on ridge in Cell B (Engineer for scale) (11/30/2021)



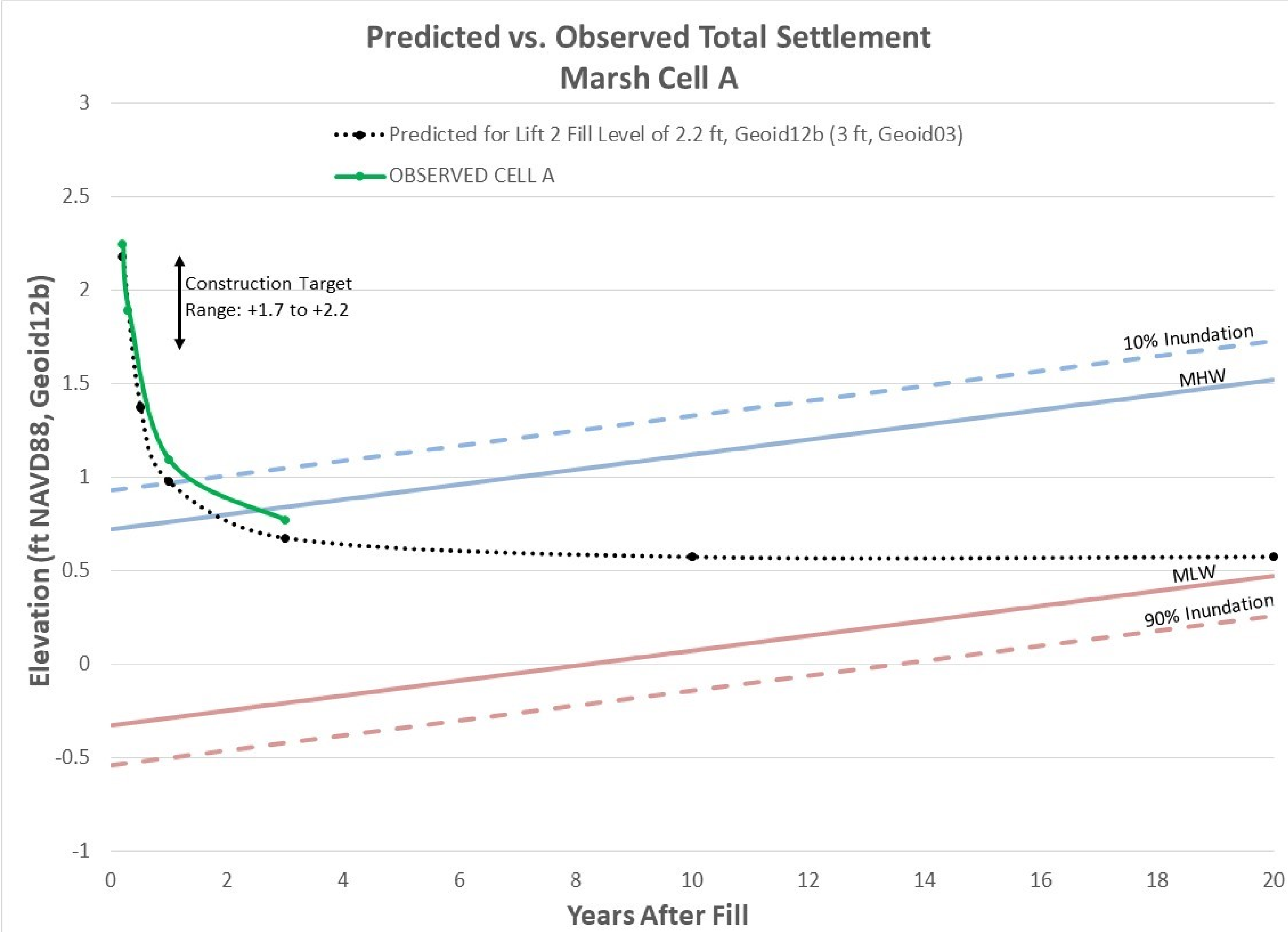
Marsh in Cell B from the Ridge (11/30/2021)

Cell C Ridge looking north (11/30/2021)

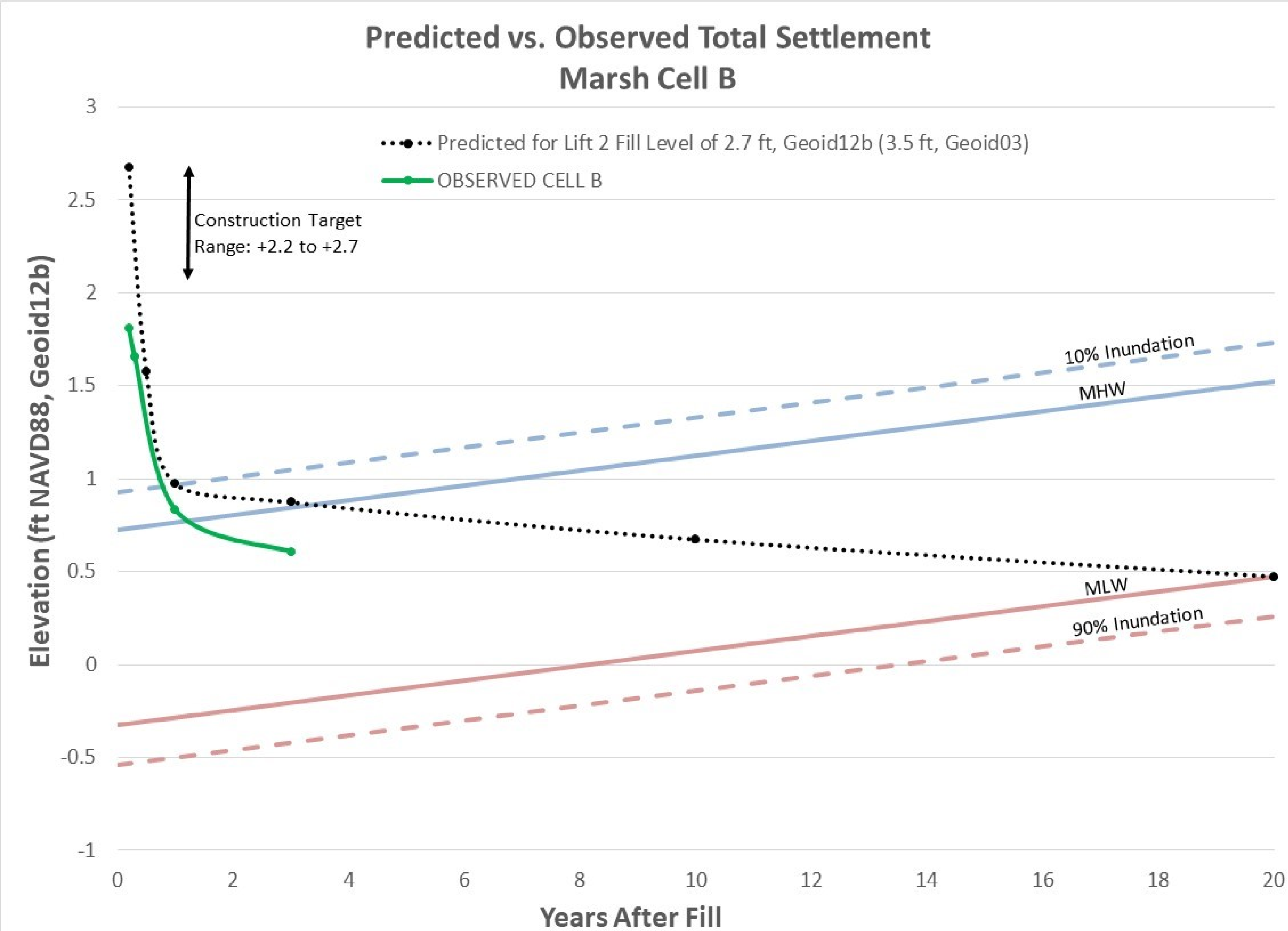
Marsh in Cell C from the Ridge (11/30/2021)

Marsh in Cell D from the Ridge (11/30/2021)

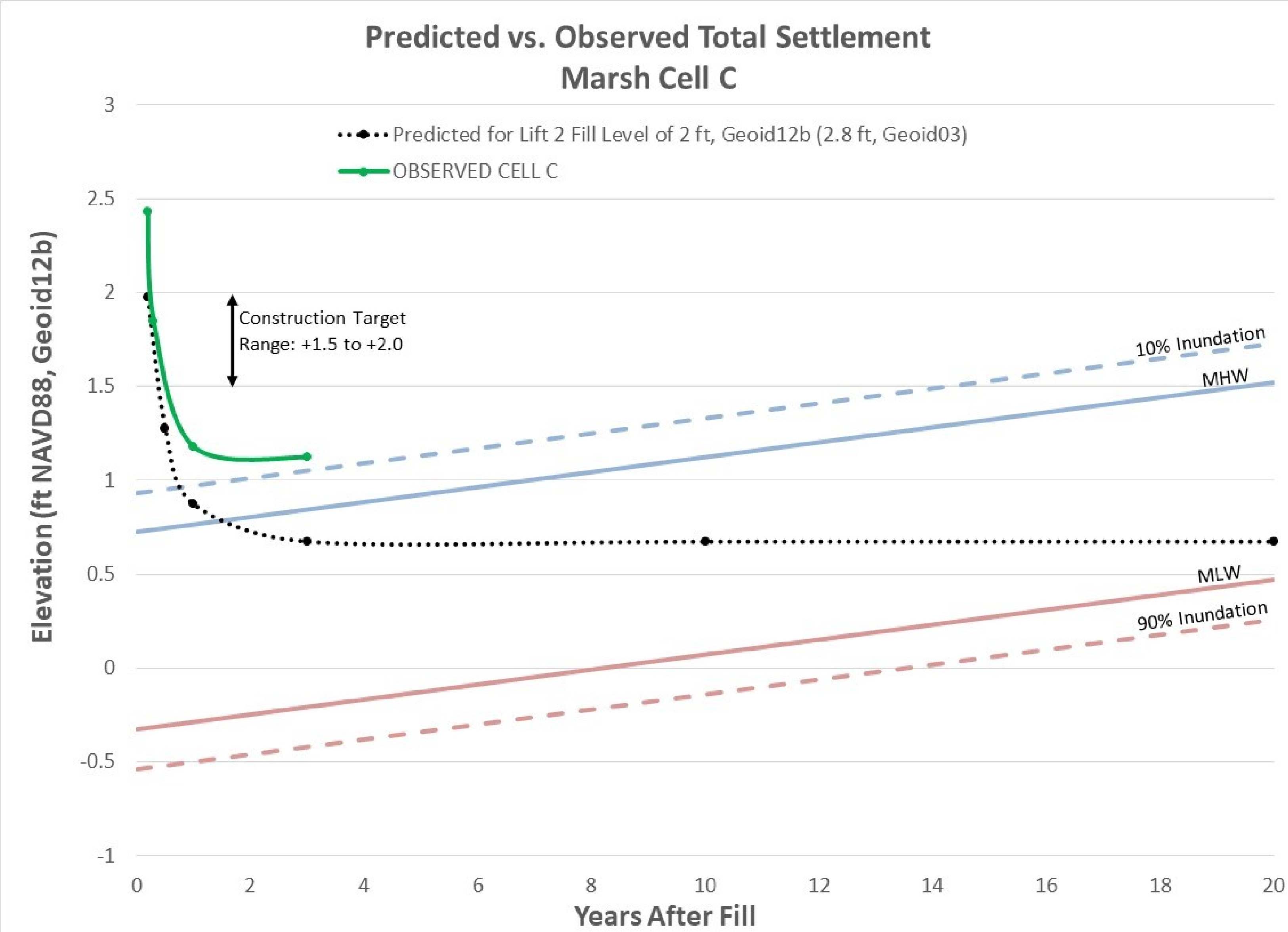
Appendix C
(Elevation Settlement Curves)



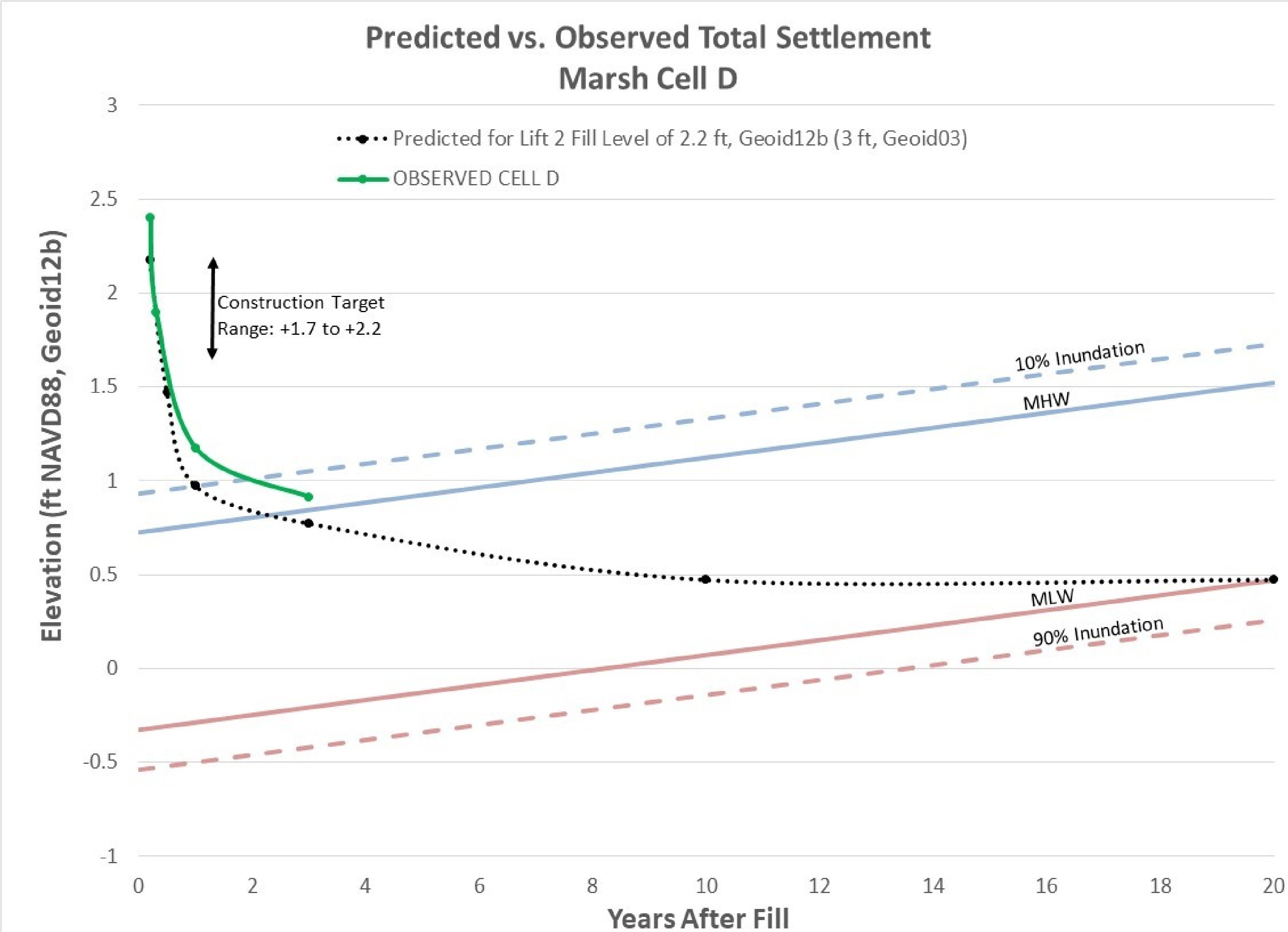
Appendix C-1. Predicted vs. observed mean elevation in BA-0068 Marsh Cell A.



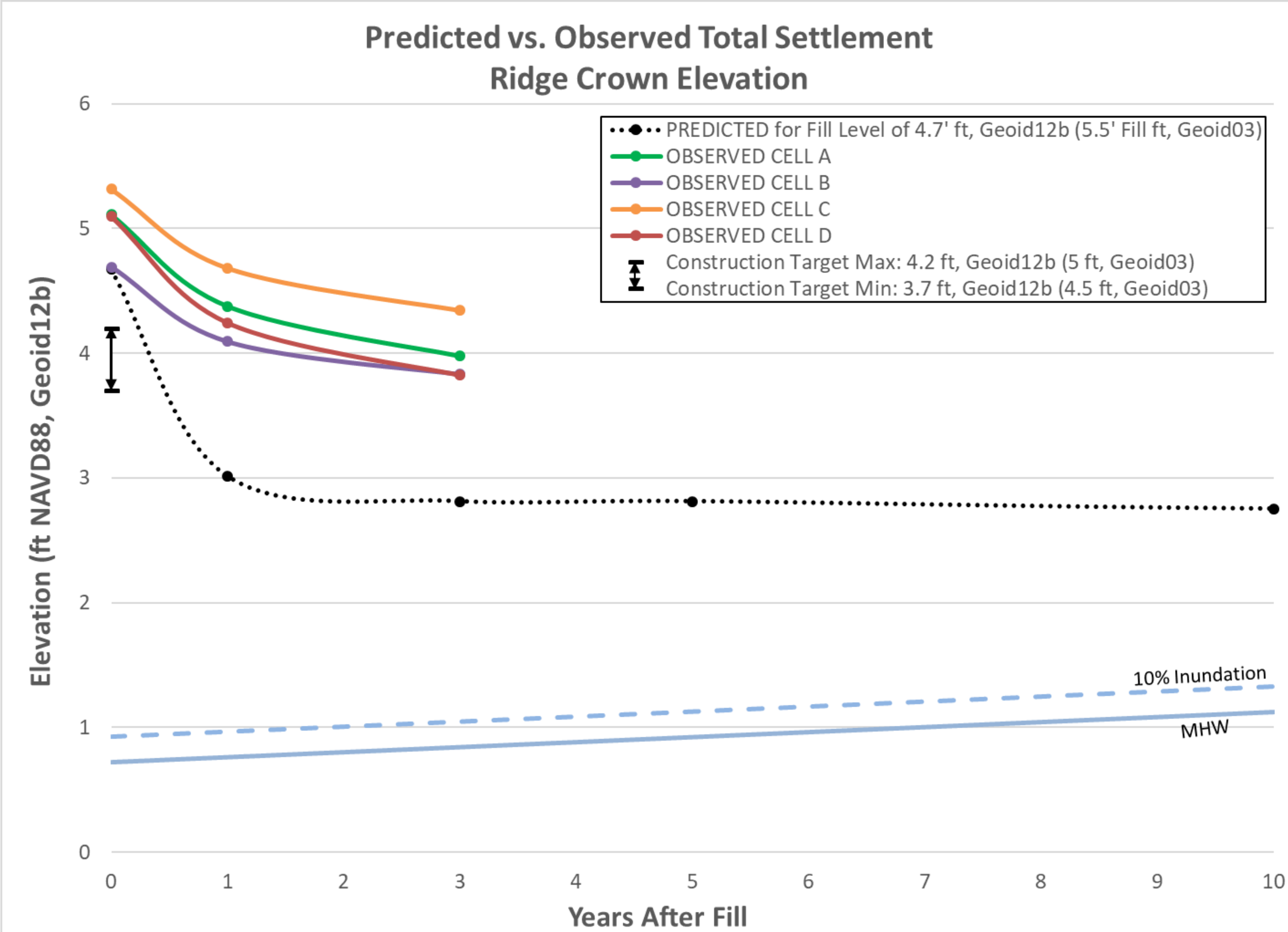
Appendix C-2. Predicted vs. observed mean elevation in BA-0068 Marsh Cell B.



Appendix C-3. Predicted vs. observed mean elevation in BA-0068 Marsh Cell C.



Appendix C-4. Predicted vs. observed mean elevation in BA-0068 Marsh Cell D.



Appendix C-5. Predicted vs. observed mean elevation of the BA-0068 ridge crown.